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THE SANTA ANA CANAL OF THE BEAR VALLEY IRRIGATION COMPANY.*

By WILLIAM HAM. HALL, M. Am. Soc. C. E.

READ FEBRUARY 6TH, 1895.

This paper is an account of the location, design, construction and cost of the Bear Valley Irrigation Company's Santa Ana Canal in San Bernardino County, California, so far as finished for use. The writer has purposely omitted all description, even in outline, of the general system of works—canal, reservoirs, pipe lines, etc.—controlled by the company, and of which this canal forms only a part, nor is the subject of water-supply for the service at all discussed. These matters may be presented in a subsequent paper. To embody them here would make this paper too long and would detract from its usefulness in the direction sought to be given it. The relation of the new canal to the older works of the company may in a general way be understood from an inspection of the accompanying map (Plate VI).

THE PROBLEM.

The main object of the Santa Ana Canal is the delivery of water for irrigation and domestic use throughout about 45 000 acres of land of the northern portion of the San Jacinto plateau or valley. These

* The Discussion and Correspondence on this paper will be published in a subsequent number.

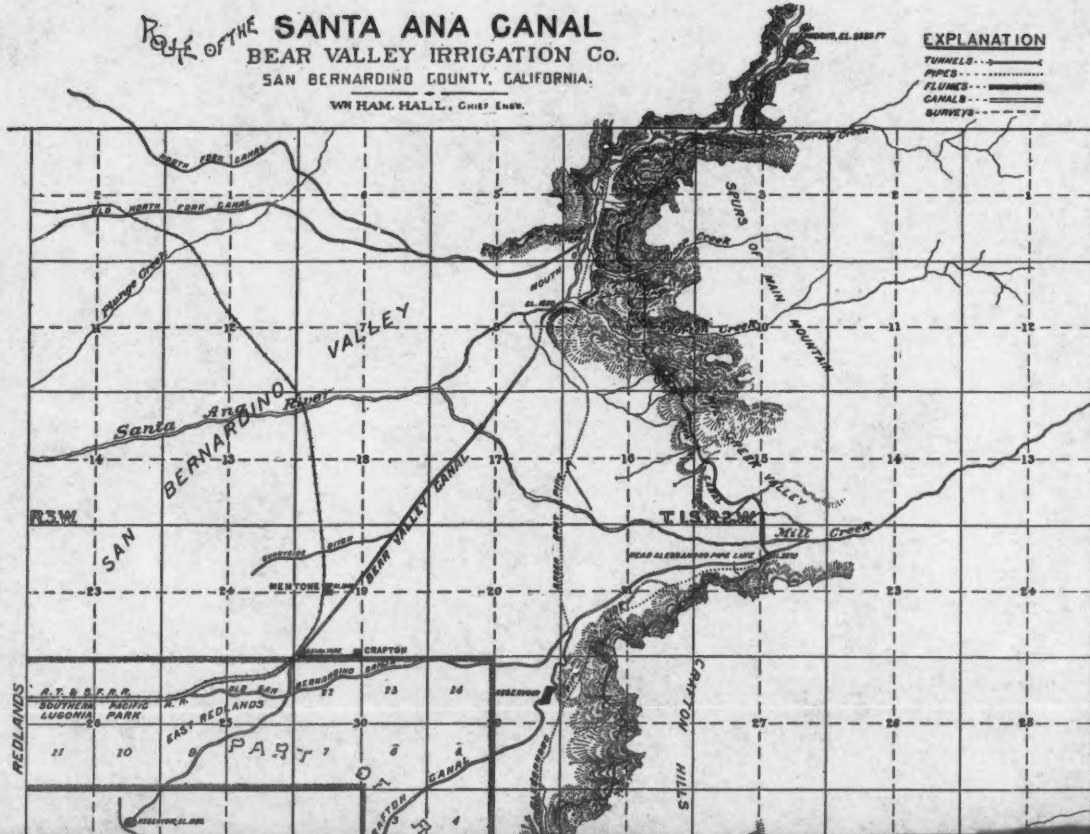
are now included in the new county of Riverside, but until recently were embraced by San Bernardino County. They lie between 1 350 and 2 040 ft. above sea level, sloping toward the south from the San Timoteo Hills, a range which extends south of east and north of west, and carries crest elevations of 2 500 to 3 500 ft. above the mentioned plan of reference.

Through a favorably low neck in this ridge, at elevation 2 050 ft. above base, a tunnel 2 320 ft. in length and of the capacity ultimately required, was located and constructed by the company about five years ago. This tunnel had been lined with brick and plastered with cement mortar in permanent work, before the location of the Santa Ana Canal commenced. Thus, the Moreno tunnel became the controlling point for delivery at the ridge when the location study was taken up under the writer's supervision as Consulting Engineer in 1891.

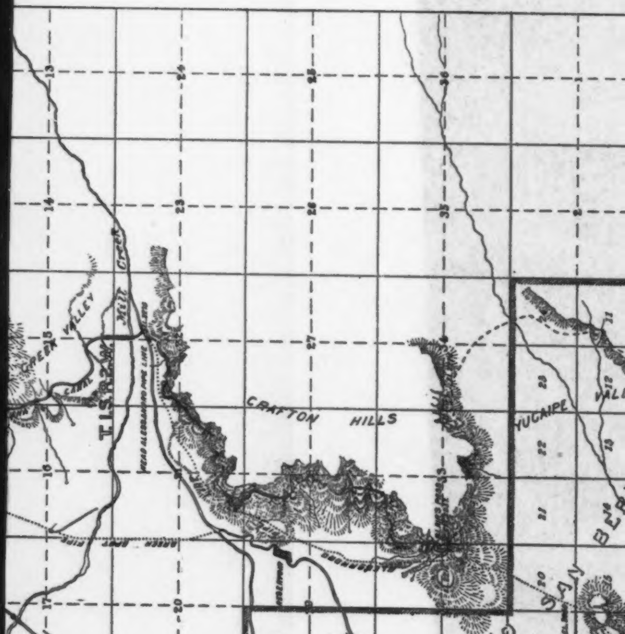
The main source of water supply for this service is the natural flow of the Santa Ana River, which is reinforced, when necessary, during irrigation months, by waters drawn from a storage reservoir within the river's water-shed in the San Bernardino Mountains, some miles above, and which are therein impounded during annual flood periods. The river debouches from its cañon course into the east end of San Bernardino Valley, at elevation 1 850 ft. above sea level, and this point of debouchment is about 10 miles in an air line (N. 19° E.) from the nearest end of the Moreno tunnel. Clearly, to deliver water by gravity flow through this tunnel, the river had to be tapped well within its cañon.

But this was not all of a controlling nature. Between the Santa Ana Cañon opening and the Moreno tunnel there lie two successive wide valleys and one long and deep cañon-like valley, with their intervening hill ranges and plateaus, and many small cañons and ridges, so that a close grade contour between these two points is probably over 35 miles, and a general contour location would probably be 30 miles in length, though the air-line distance is but 10 miles.

For the immediate purpose which was then to be subserved, the company had at the time of driving the Moreno tunnel constructed a pressure pipe line from Mill Creek to the tunnel. Mill Creek is in the first valley south of the Santa Ana Cañon opening. The pipe took supply at elevation 2 275 ft. above base, at a point 2.5 miles east of south from the Santa Ana River cañon mouth; was over 10 miles in



ROUTE OF THE SANTA ANA CANAL
BEAR VALLEY IRRIGATION Co.
SAN BERNARDINO COUNTY, CALIFORNIA.
WM HAM. HALL, Chief Engr.
EXPLANATION
TUNNELS
PIPES
FLUMES
CANALS
SURVEYS
NORTH FORK CANAL
OLD NORTH FORK CANAL
Plunge Creek
SPURS OF MAIN MOUNTAIN
VALLEY
Santa Ana River
SAN BERNARDINO
BEAR VALLEY CANAL
MILL CREEK VALLEY
R.3.W.
T.1.S.R.2.W.
Mill Creek
MENTONE
CRAFTON
CRAFTON HILLS
RESERVOIR
A.T. & S.F.R.R.
SOUTHERN PACIFIC R. R.
LUGONIA PARK
EAST REDLANDS
OLD SAN BERNARDINO
PART OF
CRAFTON CANAL
REDLANDS



CRAFTON HILLS
YUCAIPE
T.1S.R.2W.
R3W.
Mill Creek
BEAR VALLEY CANAL
CRAFTON CANAL
MENTONE
CRAFTON
SAN BERNARDINO
RANCHO
PART OF
EAST REDLANDS
A.T.&S.F.R.R.
SOUTHERN PACIFIC R.R.
LUGONIA PARK
HILLS
REDLANDS
Santa
REDLANDS

PLATE VI.
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length to the Moreno tunnel, and was calculated for 18 cu. ft. of water per second. To realize the calculated delivery, its hydraulic gradient could not be less, and, consequently, its point of intake could not be lowered. The waters it carried were borrowed from the Mill Creek zanja, or ditch, which was not controlled by the Bear Valley Irrigation Company, in exchange for waters placed in that zanja by a work of the Bear Valley Irrigation Company from Santa Ana River, at elevation 2 100, and 1.5 miles lower down. This was a temporary arrangement entered into by the company when it had to deliver a certain amount of water through the Moreno tunnel, three years and more ago, to meet its contracts, and could not then construct the Santa Ana Canal, and had no other source at command from whence the delivery could be made. When this latter canal came to location study, in 1891, and construction, in 1892-93, the water exchange contract with the Mill Creek zanja owners was about to run out, and they refused to renew it. It was impossible, both from financial and construction reasons, to build the canal all the way to the Moreno tunnel in time, and thus it had to be located so as to deliver to the head of the Allesandro pipe line as the first controlling point.

To carry the volumes of water desired, ultimately, to be brought from Santa Ana Cañon in this aqueduct (whose annual range would be between 20 and 240 cu. ft. per second), and in the class of conduits necessary to be constructed, grades approximating 0.15 to 0.2% for flume and 0.05 to 0.1% for canal channels, were desirable, as producing about the velocities which would afford economical sections and yet could be controlled.

After certain preliminary surveys had been made, the above considerations determined about the locality where the heading would have to be, and here, accordingly, a solid rock point of mountain on the east side of the cañon was selected for the headworks, where the river-bed opposite was at elevation 2 320. This point, by the river's winding course, is about $3\frac{1}{3}$ miles from the cañon opening to the valley, heretofore referred to, and the close grade contour from it to the Moreno tunnel would be about 42 miles in length, while the air-line distance is about 12 miles (S. 23° 30′ W.).

The cañon of the Santa Ana River is walled by precipitous and rough mountains and hard rock cliffs and points, except just at the opening, where high vertical bluffs of cemented gravel and boulders

stand. Between the points of diversion and the cañon opening three large and deep side cañons come from the east into that of the main river. These are known, in the order down stream, as Warm Springs, Deep and Morton Cañons, respectively, and three other lesser but notable ones, without name, exist. Between each couple of these six cañons a high mountain point stands boldly out to the main cañon's bed. Over this portion of its course the main cañon bed, or "wash," varies between 400 and 1 200 ft. in width, and is composed of a vast mass of rounded boulders (some of immense size) and gravel, with sand in protected spots, the whole mass being at least 50 ft., and, probably, at some points, as much as 150 ft. deep. The fall of this bed averages about 140 ft. per mile from the heading to the cañon mouth, being approximately 10 to 15% more than the average at the heading, and 10% less at the lower end. On this tremendous descent the river's channel, about 80 ft. wide and 5 ft. deep, winds among the boulders. The low-water flow runs down to a very few cubic feet per second when not augmented by reservoir waters; its full-water volume ranges between 500 and 1 500; ordinary floods, 3 000 second-feet; the extreme high floods, which spread out of the ordinary channel, probably reach 20 000 second-feet in volume. The roar of waters and din of crashing rocks to be here heard at time of high flood is terrific and awe-inspiring. Such are the conditions under which a diversion dam and headworks had to be planned, and hence the selection of the place for diversion in a solid rock point, where there could be no disturbance beyond the face of the gates, no matter how terrific the flood.

The Project.

The name, Santa Ana Canal, applies from this heading to the Moreno tunnel. Beyond this tunnel the work will be divided and known as the Alessandro Canal and the Moreno Canal, besides several pipe lines, by their names. To preserve order in naming of parts and for purposes of administration during construction and in accounting for costs, the main aqueduct was set out into "divisions" and "sections," each numbered in the order of occurrence from the headworks forward; each piece or stretch of work of one character of construction and forming a measurable part of the aqueduct, together with the connecting parts and the headworks, was called a "structure," and given a number in its order. Then, each trestle

support and bridge was called a "substructure," and these in like manner had numbers assigned; and, finally, each structure and substructure of its kind was numbered. Thus divisions I and II embraced sections I to XII, structures 1 to 60, substructures 1 to 46, tunnels 1 to 9, flumes 1 to 16, pressure pipes 1 to 3, canals 1 to 10, sandboxes 1 to 4, junction bays 1 to 7, besides other parts named in the schedule appended. The divisions were made according to ruling character of construction as dictated by topography; thus, division I covers the main cañon portion of the work, from the headworks out to the first broad valley encountered, that of Mill Creek; division II extends across that valley to the base of the Crafton Hills lying south of it; division III, around the north, west and south faces of the Crafton Hills to Yucaipe Valley lying next south; division IV, across that valley; whence division V reaches across a mesa or plateau country, and so on.

It was finally determined to plan the canal to carry 240 second-feet of water through divisions I and II, 300 ft. per second thence to a reservoir site on the line of the work, and then diminish to 200 second-feet for the remainder of the way to the Moreno tunnel. The latter figure represents the maximum volume which would ever be carried through any portion of the work beyond the cañon, for the purpose of direct irrigation. The larger volumes would represent its carriage when, in times of floods in the streams, which are of short duration, it was being used to fill the reservoirs. The larger volume beyond Mill Creek than above it includes the accession of flood waters it is intended to take from that stream when it is in flood; also for the storage purposes mentioned. The company's water contracts and engagements admitting, and its financial condition compelling, the course, it was determined to finish the aqueduct to half the ultimate capacity only, for several seasons' use, before completing any portion to full capacity. But all parts were to be planned and commenced for full size, and work was to be executed so as not only to save in immediate expenditure, but also to avoid waste and extra expense in ultimate finishing. With these controlling ideas the aqueduct has been put in condition for present use to half capacity as far as the head of the Alessandro pipe line—a length of 5.51 miles from the intake, and to within 1 000 ft. of the end of division II—thus practically covering divisions I and II. The total length thus finished is

29 095.3 ft., of which 18 175.3 constitutes division I, and 10 920 is in division II.

For the balance of the length of division II, and in subdivision A of division III—around the face of the Crafton Hills as far as Blair's Pass —the canal channel has been excavated for about 11 500 ft. in length, involving 50 425 cu. yds. of earth and rock work, at a cost of $24 204, or 48 cents per cubic yard; and 1 400 ft. of flume bench, involving 5 318 cu. yds. of material, at the same rate, cost $2 739 52. In this same division III, 1 284 ft. of excavation has been completed in three tunnels, at a total cost of $6 931 50; but these are not completed. All this work was done by contract. The topographic and preliminary location surveys have been carried to Moreno tunnel, the proposed end of the main work.

This paper deals with the parts made ready for use in divisions I and II to the head of the pipe line only. Although this covers but about one-sixth in length of the work, and, for the most part, is finished only to half capacity, the accomplished portion embraces nearly all the heaviest, and covers an unusual variety of, construction. The writer seeks herein to give prominence to those features which are thought to be novel, or which may be interesting because unfamiliar to the profession in other quarters. The balance is embodied for sake of completeness of the article and as a location and cost study.

Construction Narrative.

Construction commenced in the middle of December, 1892, but was not well under way until a month later. The heavy work was done by the middle of July, 1893. The force was thenceforward gradually reduced and the main construction was finished about the last of August, there being some odd jobs only, which occupied a very small force a while longer. Carried promptly forward, with means at command as required, the work could have been well accomplished in five months without rush or waste. Throughout, the company was in financial straits, and although provision was made for absolute necessities, and the force stuck to the work until finished as above, a demoralizing fear of failure and shutting down continuously prevailed among all classes of employees. For the four months of heaviest force account the pay days were much delayed; later, they failed to materialize at all; a panic and strike was daily feared. A spirit of

feverish unrest and uncertainty prevailed, and it is not too much to say that, from this cause, for a large part of the time, the efficiency of labor was reduced as much as 25%, and on some works as much as 40%, and its results correspondingly increased in cost. The same general cause resulted in paying higher prices than ordinary for materials of all kinds, and incidental expenses were run up in proportion.

Very much of this was unnecessary and the direct sequence of a short-sighted business management at the outset. The company started in to pay cash for everything. At first, pay-rolls had to be made out and audited so that all employees could be paid off in cash by the 3d, and then the 5th, of each month, for the month preceding; and merchant bills had to be audited for payment by the 10th. Every laborer who chose to leave work at any time during the month was permitted to draw his pay in cash, and not required to wait for a pay-day, as those who stayed on the work had to. Consequently, the employ came to be a tramp's entrance-way to paradise—a few days' work now and then enabled him to get the cash to loaf on for a week or two. The system of time checks, redeemable after 30 to 90 days, was not known. The consequence was that the company established no local credit for its small paper among merchants and others of the towns and country around. The system had not been put in use at the time when its general credit was good, and, consequently, when its greater financial troubles came, it had not the local support it should have received. Used to being paid in cash promptly within a few days after the close of each month, the employees were demoralized when a pay-day was delayed, and stampeded when time checks were issued in place of coin. When the local merchants refused to take the time checks in trade, a crisis was brought on and a general strike and suspension of work seemed imminent. Whole gangs of laborers could be seen along the line during working hours, calmly seated or leaning on their shovels discussing the situation. Teamsters, with high-paid four-horse teams, let their animals get fat on what should have been very hard and exhausting work. The general superintendent of the labor force was, by business arrangement with the former management, also the force boarding contractor and camp sutler (an arrangement, bad, from whatever point it is viewed), and the company ran largely into his debt; he became involved heavily with his supply merchants; the nervous strain demoralized and broke him down, and the watchful-

ness, vigor, activity and tact of good superintendence, of which at such a juncture the company should have had the benefit, was totally lacking. The situation was unfortunate and disheartening to a degree that was calculated to drive a responsible engineer into an asylum.

It is not for a moment thought that a wiser initial business policy with respect to these matters would have saved the company from its final disaster. The point is, that such wiser policy would have averted much trouble during the construction period, and would have kept the cost at least several thousand dollars within the estimate, instead of allowing it to run over. Nevertheless, as against a final estimate of $167 000, the work was finished at a cost of $189 600. Excess, 13.5 per cent.

And this actual result included costs not originally estimated upon at all; as, for instance, $5 650 for roads and crossing bridges. A comparison of the total amount of corresponding items, covering the cost of the work proper, makes the excess of cost about 8.6% over the final estimate. An estimate of waste due to the unfavorable conditions commented on shows that the cost would have come about 5.4% within the preliminary estimate if the work had been carried on under normal conditions and efficient superintendence.

Owing to causes which it is out of place here to discuss, but which were in no degree whatever affected by the results of this or any of its construction expenditures, the company went into the hands of a receiver in December, 1893. It is yet thus held. There is a probability that the property will be sold to a new organization, under an arrangement thought to be such that the works will be carried to completion substantially as originally planned.

Engineering Cost Accounts.

By a system of time cards and daily force reports, to account for distribution of labor of each class on every work or structure, and on each class of construction in it, and by charging materials to structures wherein used, and keeping memoranda of use of materials within and circumstances of work on each, an attempt was made to preserve a thorough account of cost. Had the company's financial troubles not complicated and obstructed this duty, the outcome would have been gratifying, at least to the engineers engaged on the construction.

As it is, the statements of cost—though quite complete and sys-

tematically worked out from data regularly collected throughout—are to be taken with a grain of salt. The Bear Valley Irrigation Company was not in financial condition to commence a great work when it began this, and from the times of letting the first (the tunnels) contract and arranging to have a day-labor force put into the field, it was at a disadvantage to secure economical construction. Moreover, as already explained, for the last half-period of the work the force was peculiarly demoralized; everything tended to relaxation of system and care. The duty of enforcing these without overstraining was a delicate one. From personal notes by the writer and his immediate assistants, in addition to the accounts referred to, an attempt is herein made to establish a size for the grain of salt to be taken. Thus, to many concluding figures of cost given, supplementary ones are added, expressing much more nearly what, under normal conditions and good superintendence, the cost would have been.

It would be easy enough to pass these matters over and give an account of this work, implying that it cost no more than it should. As a matter of fact, considering its complexity and the novelty of many of its important parts, it did not cost more than it would had it all been carried out by contract in the ordinary way. The contractors might legitimately have made about the difference—say 20 to 25%—on the part affected. But when an engineer has labored, with a faithful force of competent assistants, to keep the cost of a notable and complicated work within a carefully prepared estimate, with a hope of making an example useful to the profession, and it unnecessarily exceeds that estimate, the writer thinks it a duty to the profession to bring out the facts. There is no reason for this in the way of personal vindication. The company officers and principal shareholders know and appreciate the cause for the excess of cost over the estimate. The engineers have not been blamed. Neither has the cost been commented upon as high, considering its class, by any one, so far as the writer knows. On the contrary, engineers of experience visiting the completed work have expressed satisfaction at its apparent reasonable cost, in view of character and locality. The reason for higher cost than was estimated, though, affords an example of a subject which, it is thought, the profession may profitably consider. As the writer has not noticed discussion of this subject before the Society, he ventures to present this example.

It may not be amiss here to say, that of all engineering service the keeping of thorough and really useful accounts of cost and performance of work the writer has found the most difficult to secure. It is not so much to be wondered at that business managers and foremen, or even superintendents, may not appreciate the utility of such data; but, to the writer, it is inexplicable that engineers who are responsible for plans and estimates, or who hope some day to be in a position to have such responsibilities, should be willing, even, to have important work go on under their direction without a record in all possible detail being made of its cost and progress.

Yet it is the exception when any such record is kept on Pacific Coast works, and many civil engineers in this region habitually demur to taking any such trouble, or they look upon an attempt at making it thorough as impractical, or declare that it simply cannot be done, or is putting on the employer a useless expense. Why should we not always know, in utmost detail, the cost of our works, as principal manufacturers and machine-shop men know to a cent what every article of their output has cost?

The Bear Valley Irrigation Company's recent work in this respect afforded an exception to usual Pacific Coast experience. The general management was in accord with the chief engineer in the desire to do good permanent work at a minimum cost to the company, and to keep an honest and thorough engineering account of it; and the engineering assistants were generally anxious to keep track of the construction details and expenditures. But the company's financial quaking not only embarrassed the manager, but kept even the engineers in a tremor. The greatest obstacle, however, was the viciously foolish arrangement, carried over from the company's former way of doing business, which fixed the superintendent of the common labor and teaming work as the boarding contractor for the day force, and so, during the financial trouble, put the work at his mercy. It is this to which attention is invited.

Observe the bad points in such an arrangement as affecting this matter of cost-account keeping.

From the very beginning the interests of the superintendent were centered in his boarding camps and not on the company's work, for had the men been paid promptly (their board accounts being regularly deducted and paid to him), he would, with his commissary store on the

works, have cleared at least $500 per month, while his salary as superintendent was only $130 per month. His interest lay in keeping men satisfied with him, whether they rendered the company good service or not. And, then, when the company ran heavily into his debt, what could be done? Had another superintendent been put in, there would have been trouble, probably a strike and failure to finish the work in time to carry water to save the company's engagement, for the men were naturally the adherents of the boarding-boss superintendent.

Another boarding contractor could not at that time have been induced to put camps into the field, and the company was not in condition itself so to do. Then followed the stage when the superintendent himself got into trouble. The company owed him $12 000 to $15 000 on board account, and the debt was increasing; he owed for supplies probably half as much, and his creditors were pressing him and threatening to foreclose on his property, for the company, his sole large debtor, was known to be in a precarious condition. The strain broke him down, nervously, and the work was virtually without vigorous handling for several months. The engineers could do nothing but hopefully cheer up the superintendent and foremen, quietly appeal to the better feelings of the men, occasionally make just a little row about the work, and generally wink at the poor service the company was getting.

And this poor service was confined not alone to the greater labor and teaming force under the labor superintendent in question, but it extended, in a somewhat less degree only, to the carpenters' force under another superintendent, although he was a most competent, faithful and energetic man throughout; for, be it understood, that the entire day labor force boarded at the one set of camps, and all became impregnated with the contagion.

The daily reports of the greater labor and teaming force were made out in the camp office of its superintendent from data which his foremen furnished on the ground, by the superintendent's timekeepers who collected the men's time for the pay-rolls. This arrangement was a mistake. The distribution of labor and consumption of material should have been daily ascertained and formulated in the engineer's office by inspectors especially instructed and competent to judge as to plans and parts of structures and classification of construction work The error was sought, after the work was well under way, to be reme-

died by appointing a special engineering accountant to supervise the making of daily reports from time to time; and, still later, by putting an engineer on duty as inspector to keep notes to check and amplify the timekeeper's daily reports; but the remedy was not all that could be desired. The mistake was made at the time when the superintendent was engaged under an arrangement which made it impossible, under the circumstances which followed, to change either him or the system after the work was well under way. Such an arrangement was an injustice to all interested elements—even to the person thus kept in so anomalous a position—as well as to the work. It was a legacy from a former management and not the fault of that which controlled during construction.

Routes.

Although for the route selected and since in part built upon, the location was controlled as already explained, and although the Moreno tunnel had been placed with the special view of its being a link in the chain of structures on this special route, when final location of the canal came to be made there was a strong element in the directorate of the company, not unsupported in its engineering department as then organized, which strenuously favored a route much higher on the general slope of the country. Moreover, the choice between these routes had for several years been a subject of debate and even dissension in the company's managerial councils, which had shaken the organization and had even caused the upsetting of a former business and engineering control.

By the upper route, diversion would have been made from the river at about elevation 3 800 ft., and after a rugged mountain course for the conduit of 7½ to 8 miles, and with several very long tunnels, the waters would have been dropped into the shed of Mill Creek; then, rediverted from that creek at about elevation 2 800 ft., they would have been carried across a plateau behind Crafton Hills, and thence, dropped to the Moreno tunnel or some other passage of the San Timoteo range.

The upper route was acknowledged to be far the most expensive for that portion between Santa Ana River and Mill Creek, but was claimed to be much the cheaper from thence to the San Timoteo Hills; it commanded additional lands and was thought by its advocates to be, all things considered, the cheapest.

A discussion of the relative merits of the two routes, with their influencing conditions and business complications, would be foreign to the purpose of this paper. The deciding argument in favor of the route selected was, that by it alone, within the time allowable, was it possible to bring water belonging to the company to the head of the Alessandro pipe line; and connected canal construction beyond that point could not be thought of until at least one, and, probably, two, seasons later.

This choice of routes and the complications produced thereby is adverted to here, and the existence of other influencing circumstances is hinted at, for the purpose of bringing to mind the difficulties and embarrassments under which the consulting engineer is often compelled to act, and for the purpose of showing the very wide range which this canal location study was forced to take.

Months and months of time and thousands and thousands of dollars had been expended by this company before the writer was called, as consulting engineer, to its councils, on surveys connected with the question of its water delivery. Yet, when the time came for the decision, the data were not available on which intelligently to arrive at one. Then, necessarily, came other months of examination and expenditure, and, finally, a decision forced on a point not involving the real merits of the case at all. Those who have our great enterprises in management, during their initial stages, have much to answer for.

It is not to be inferred that the writer thinks the wrong route has been selected for the Santa Ana Canal; there is no opinion on that point hinted at herein; but with all the advantage of time and money which was commanded and spent, here was a really great engineering and economic problem decided without going into its merits.

Engineers in the future may study this location with the advantages of perfect topographic maps covering the whole related territory. Suppose a better location, all things considered, is to be found on the upper route; in the absence of a distinct explanation of the circumstances, it probably would be incisively said, that the man who determined the route for the Santa Ana Canal did not know what he was about, or was influenced otherwise than by proper considerations, for the archives of the company would show that extensive instrumental examinations were made, and tradition would be to the effect that much time, money and talk had been expended on the problem. By such

appearances is our profession too often judged. Engineers who have its interest at heart should, as early as possible, but, at least, before closing their careers, make an available record of the true stories of such cases in their experience.

Location.

The lower route having been determined on, the location was studied upon the basis of carefully prepared topographic maps drawn to a scale of 50 ft. in the inch, and showing 5-ft. contours. These maps, for the cañon portion of the route, were platted from cross-section notes based on two connected and approximately parallel preliminary lines—the contour curves being drawn in the field, to catch intervening irregularities of the formation. The two controlling preliminary lines, carefully run in with transit and chain, and frequently connected, had a vertical interval of about 70 ft. The space between, as well as for about 30 ft. in elevation above the upper line, was closely contoured. The provisional location was projected by tangent and curve, on the maps in the office, and was laid on the ground by instruction notes made from the projection, and with the benefit of the map carried into the field for reference on a plane table.

On the basis of this provisional location, more accurate cross-sectioning was made, and from notes thus obtained a new and very close contouring of the ground was drawn in the field, upon plane table sheets, on a scale of 30 ft. in the inch. The sheets thus prepared were as accurate and full in every detail of topography of the line as they could well be made. With the first location profile also at hand for guidance, a final location project was laid down on these sheets, and carefully connected with the first location. This final location was then laid on the ground, in the manner described for the first one, and cross-sectioned for grading. And, still again, after the bulk of the rough grading was finished, the location line was again run out, offsets were taken to the grade-contour and bench's edge, and the construction line was, in places, more closely adjusted by these last data.

The object of this exceptional amount of care in location was to place a flume along the cañon's side, whose total curvature should be kept down as much as possible, whose maximum degree of curvature should not, at any point, exceed a desired limit, whose curves should be all adjusted to a few standards, and which should rest on solid and

PLATE VII.
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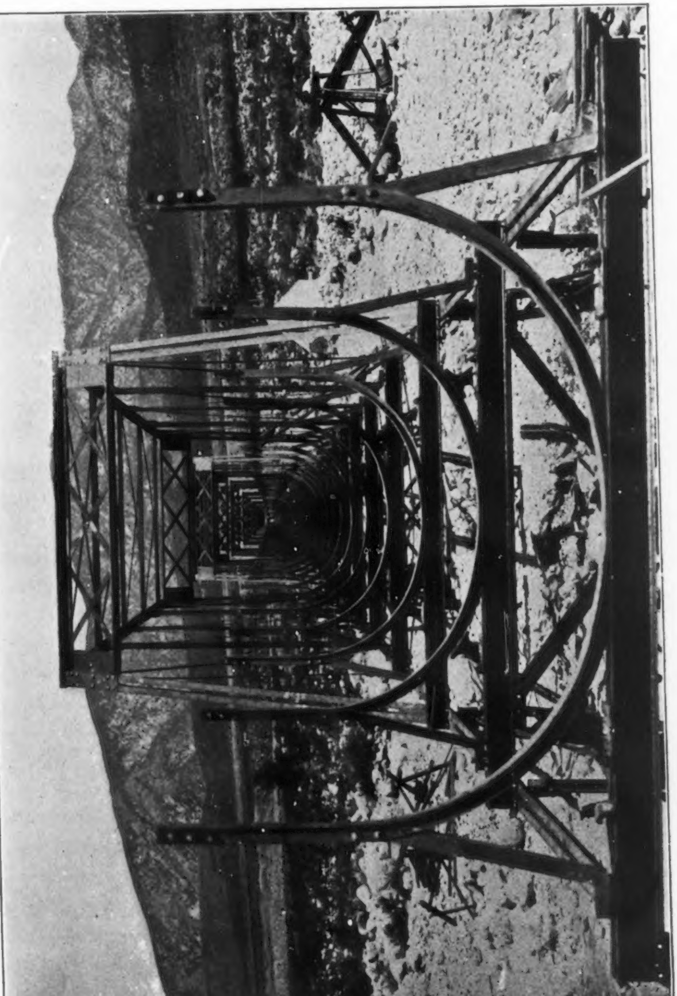


full-width bench as much as possible—thus limiting posting and trestle, and truss supports to a minimum—and yet avoiding unnecessary and expensive rock work. After the bench was graded, centers were instrumentally set for each bent of flume (every 8 ft.) on curve and tangent, and every footing, of which there were three to the bent, was staked by the engineers.

The instrumentation throughout turned out excellently well, reflecting credit on the assistants in charge and the instrumentmen under them. When it is known that much of this cañon side was so steep and rugged as to have been impassable before a trail was graded along it, even necessitating the use of hanging ropes to get along by, in places for several hundred feet at a stretch, and at other points, because of cliffs, not accessible at all, and that the cross-cañons were sharp and deep and the intervening points or ridges high and precipitous, it will be understood that surveys had to be repeated and checked again and often, to insure against mistake or error from accident. The tunnel alignments and grades, of which there were two about 1 500 ft. in length each, came out, on driving from opposite ends, within half an inch as a maximum error, though in neither case were the circumstances specially favorable for getting good sights away from both tunnel portals or for leveling over the mountain spurs pierced.

In division II the original topographic maps were made in the field directly on plane-table sheets, upon the basis of transit preliminaries staked in long tangents, and following the general line of grade contour, as flagged out in advance by the level. These sheets were on scale of 50 ft. in the inch, and had contours at vertical intervals of 2 to 5 ft., according to the degree of smoothness and transverse slope of the ground. Upon these sheets, as in the case of division I, a line of location was projected, and this line was run by instruction notes. On the basis of the profile of this provisional location and cross-sections therefrom, without making the larger scale topographic sheets, the final location in this division was adjusted. Though having a general appearance of smoothness as a sloping valley plain, the country transversed in this division was really rough in detail and much cut up by gulches, and the materials to be handled were, generally, heavy. The desire was to locate the canal as nearly as possible in exactly that amount of cutting which would keep its lining to the full water plane in earth, keeping down unnecessary

cutting, avoiding fills, limiting lengths of trestle and flume across gulches, and preserving directness and ease of alignment.

Construction Organization, Etc.

In division I all work, except the driving of the first eight tunnels and the construction of the three pressure pipes, was done by day labor under a company superintendent and foremen, supervised by the engineer in charge only as to technical method, adherence to plans and specifications, and acceptance of results. The handling of the force was exclusively under the superintendent. In division II the canal was excavated, but not trimmed, by contract, and all else was done by the day-labor force, as above. The company secured three acres of land for construction yards, well located where a spur from each of the two great railway systems of the country could be brought in, and here all materials were delivered f. o. b. cars. A wood-working mill, iron-working shops, and dipping vats and other conveniences were set up, and all framing and manufacturing was here executed, except making the frames and other heavy iron parts of flumes and of the steel bridge, which were delivered at the yards as manufactured material, and put up in the field and riveted, etc., by day labor. The yard was favorably located for delivery thence to the works, 3½ to 7 miles distant, and hauling therefrom was contracted at 37½ cents per ton per mile (including loading and unloading) for delivery to certain designated and numbered stations along the route, whence subdelivery was effected up the cliffs and along the work by day labor and company apparatus. The company was at the expense of all road building and maintenance, which, as will be seen, constituted no inconsiderable item of cost.

Description of the Works.

The intake, with its floor 2 323 ft. above base, is in the vertical face of a solid rock point, and a tunnel thence, 220 ft. in length through this point, brings the work out to where a side cañon enters, carrying at time of heavy rains a mass of detritus. To avoid taking this into the conduit—it being impossible to go around and over it without coming within reach of river flood waters—the location was kept into the hill, and the work so built, as a walled canal in cutting, that the side torrent might be carried over it.

Thence onward through division I the aqueduct rapidly "climbs"

the cliffs and mountain side—for the cañon-bed drops away at rates from 160 to 125 ft. per mile, while the flumes, tunnels and pipes have hydraulic gradients averaging less than 10 ft. per mile—and, by tunneling the spurs and spanning or piping the cañons, follow a contour of the mountain wall not materially longer than the general alignment of the cañon-bed itself.

Altogether, nine spurs are pierced by tunnels, whose aggregate length is 4 328.8 ft.; three cañons are crossed by pressure pipes, whose total length, as measured horizontally in the line, is 2 127.3 ft.; nine reaches of flume, having an aggregate length of 11 394.3 ft.; one piece of walled canal of 152 ft., and eight masonry walled structures in the nature of sand-boxes, junction bays and wasteways or outlets, measuring 173 ft. in line, make up the aqueduct as now finished for use in division I. In this division also there are 39 substructures, in the nature of trussed girders or combination Fink truss spans, resting upon timber piers on masonry footings, and these have an aggregate length of 1 905.5 ft.

In division II, as now finished for use, there are, inclusive of 40 ft. of junction bay, eight stretches of canal having a total length of 8 214 ft., all of which is lined with rubble in mortar except 482 ft. in fills temporarily lined with wood. Alternating with the canal reaches are seven reaches of flume, aggregating 2 706 ft. in length, crossing six sharp gulches and the wide flat torrent bed of Mill Creek. The gulch crossings are held by string girders and trussed wooden girders upon wooden piers on masonry footings, having an aggregate length of 1 440 ft.; and Mill Creek crossing is made by a riveted steel bridge 1 072 ft. long.

The following schedule names and numbers the several parts or structures of the aqueduct, and gives the length of each in the line:

STRUCTURE SCHEDULE.—DIVISION I.

Sec.	No.	Name.	No.	Feet.	Remarks.
I	1	Diversion dam...	..	......	Diagonally across cañon. Not built.
".....	2	Wasteway........	1	......	Sluice and river by-pass. Not built.
".....	3	Headworks	..	......	Not complete.
".....	4	Tunnel...........	1	216.0	Fully complete for 240 second-feet.
".....	5	Walled canal	..	152.0	Torrent crossing, 60 ft. Complete.
".....	6	Flume.	1	328.0	Finished for 120 second-feet.
".....	7	Sand-box.........	1	64.0	" " " " "
".....	8	Flume	2	2 127.0	" " " " "
".....	9	Tunnel	2	208.0	Fully excavated, not lined.
".....	10	Flume	3	118.5	Finished for 120 second-feet.

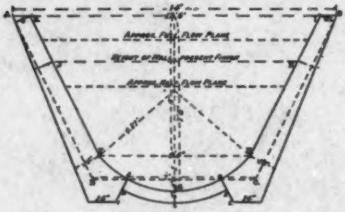
STRUCTURE SCHEDULE—DIVISION I—(*Continued*).

Sec.	No.	Name.	No.	Feet.	Remarks.
I.....	11	Sand-box..........	2	......	Not built. Will replace part of flume No. 3.
".....	12	Wasteway.........	2	......	Not complete. Will replace part of flume No. 3.
".....	13	Tunnel	3	236.0	Fully excavated. Not lined.
".....	14	Flume	4	580.8	Finished for 120 second-feet.
II.....	15	Junction bay	1	17.2	Fully complete for 240 second-feet.
".....	16	Pressure pipe....	1	540.0	Across Warm Creek. One pipe built.
".....	17	Junction bay	2	15.0	Fully complete for 240 second-feet.
III....	18	Flume	5	1 738.0	Finished for 120 second-feet.
" ...	19	Wasteway.........	3	......	Incomplete. Will replace part of flume No. 5.
" ...	20	Tunnel	4	54.0	Fully excavated, but not lined.
" ...	21	Flume	6	2 418.0	Finished for 120 second-feet.
" ...	22	Wasteway.........	4	......	Not built. Will replace part of flume No. 6.
IV....	23	Tunnel	5	1 410.0	Fully excavated. Not lined.
V.....	24	Flume	7	2 688.0	Finished for 120 second-feet.
".....	25	Wasteway.........	5	20.0	Also outlet to drop to lower canals.
".....	26	Tunnel	6	58.0	Fully excavated and lined.
".....	27	Flume	8	229.0	Finished for 120 second-feet.
".....	28	Tunnel	7	43.0	Fully excavated and lined.
".....	29	Flume	9	1 167.0	Finished for 120 second-feet.
VI....	30	Junction bay....	3	17.0	Fully complete, for 240 second-feet.
" ...	31	Pressure pipe....	2	908.2	Across Deep Cañon. One pipe built.
" ...	32	Junction bay	4	17.5	Fully complete for 240 second-feet.
VII...	33	Tunnel	8	1 594.0	Fully excavated; partly lined.
VIII..	34	Junction bay	5	16.3	Fully complete for 240 second-feet.
" ...	35	Wasteway.........	6	......	Not built. Temporary flume built.
" ...	36	Pressure pipe....	3	679.0	Across Morton Cañon. One pipe built.
" ...	37	Junction bay	6	6.0	Penstock. Complete for 240 second-feet.
IX....	38	Tunnel	9	509.8	Complete, 240 second-feet.
				18 175.3	3.442 miles.

DIVISION II.

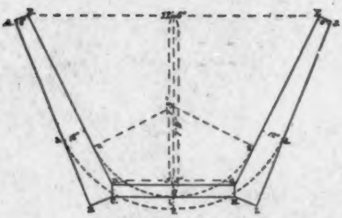
Sec.	No.	Name.	No.	Feet.	Remarks.
X.....	39	Junction bay	7	40.0	Incline. Lined for 140 second-feet.
".....	40	Canal	1	1 344.0	Lined for 120 second-feet.
"	41	Flume	10	141.0	Finished for 120 second-feet.
".....	42	Canal	2	244.0	Lined " " " "
".....	43	Flume	11	200.0	Finished " " " "
".....	44	Canal	3	275.0	Lined " 240 " "
".....	45	Flume.	12	328.0	Finished " 120 " "
".....	46	Canal	4	951.0	Lined " " " "
".....	47	Flume.	13	416.0	Finished " " " "
".....	48	Canal	5	527.0	Lined " " " "
".....	49	Flume	14	192.0	Finished " " " "
".....	50	Canal	6	758.0	Lined " " " "
".....	51	Flume	15	214.0	Finished " " " "
".....	52	Canal	7	3 569.0	Lined " " " "
".....	53	Wasteway.........	7	......	Not built. Will replace part of flume No. 16.
XI....	54	Flume	16	1 215.0	Across Mill Creek. Finished for 120 second-feet.
XII...	55	Sand-box..........	3	......	Not built. Will replace part of flume No. 16.
" ...	56	Canal	8	506.0	Finished for 120 second-feet.
" ...	57	Pipe heading.....	..	......	Alessandro pipe line.
				10 920.0	= 2.068 miles.
		Total		29 095.3	= 5.51 miles.

Fig. 1



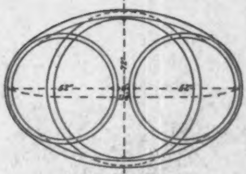
Canal Lining - Division II - Construction Lines Adopted.

Fig. 2



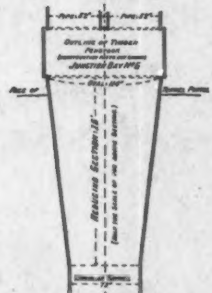
Canal Lining - Comparative Sections - Construction Lines Not Adopted.

Fig. 3



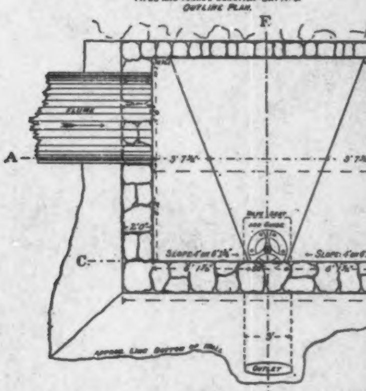
Pipes and Tunnel Junction Sectional View.

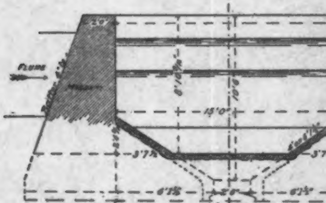
Fig. 4



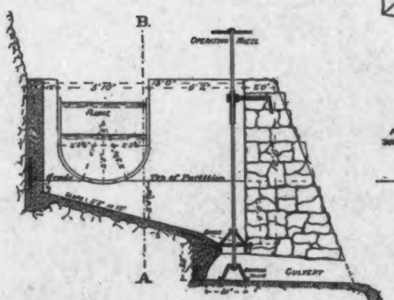
Pipes and Tunnel Junction - Bay No 6. Outline Plan.

PLAN AND SECTIONS
SAND-BOX No 1
DIVISION I





Sand Valve
With Seat and Guide
3" = 1'



Sectional View Line E.F.

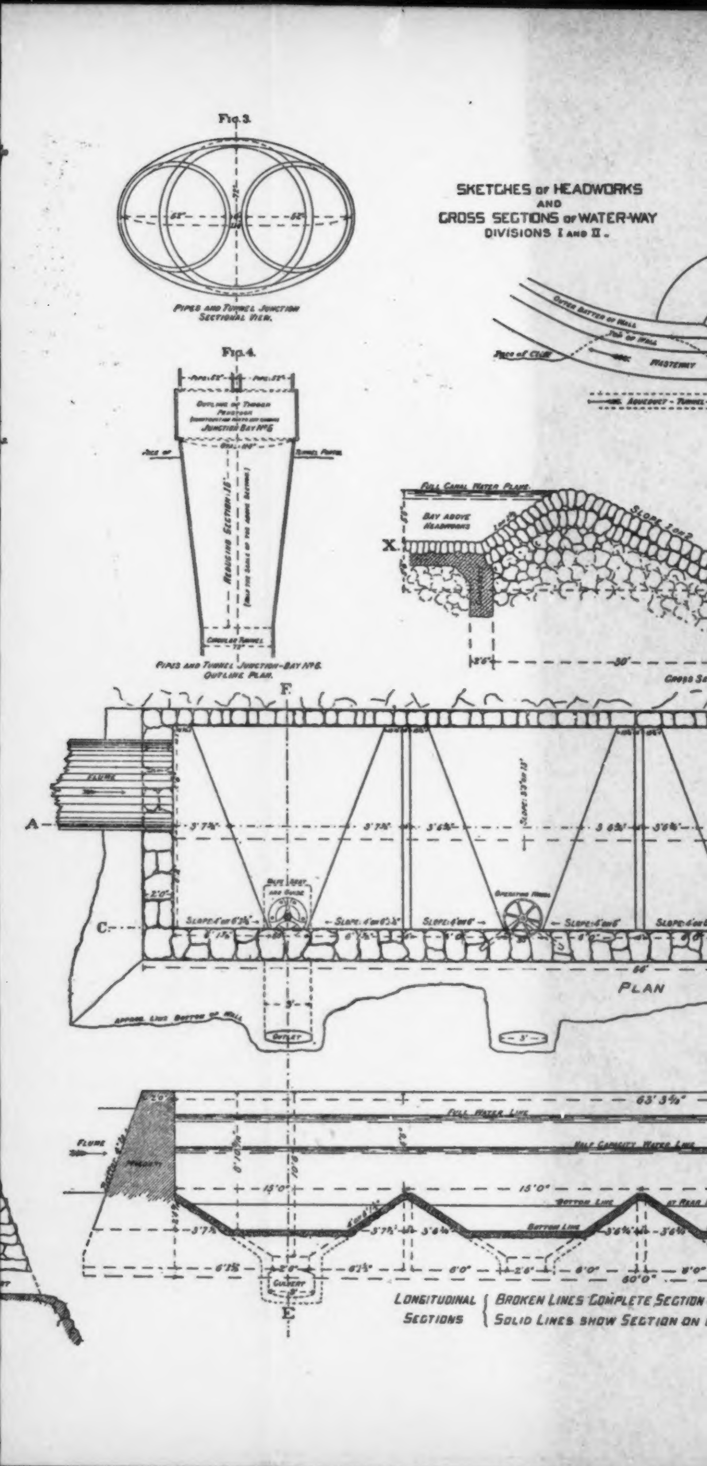

SKETCHES OF HEADWORKS
AND
CROSS SECTIONS OF WATER-WAY
DIVISIONS I AND II.
Fig. 3.
PIPES AND TUNNEL JUNCTION
SECTIONAL VIEW.
Fig. 4.
JUNCTION BAY No 6
REDUCING SECTION: 18'
CIRCULAR TUNNEL
PIPES AND TUNNEL JUNCTION-BAY No 6.
OUTLINE PLAN.
OUTER BATTER OF WALL
TOP OF WALL
FACE OF CLIFF
WASTEWAY
AQUEDUCT - TUNNEL
FULL CANAL WATER PLANE
BAY ABOVE HEADWORKS
X.
SLOPE 2 ON 3
F.
A
C.
FLUME
PLAN
OUTLET
OPERATING WHEEL
APPROX. LINE BOTTOM OF WALL
63' 3½"
FULL WATER LINE
HALF CAPACITY WATER LINE
BOTTOM LINE
15'0"
60'0"
MASONRY
CULVERT
E.
LONGITUDINAL SECTIONS
BROKEN LINES COMPLETE SECTION
SOLID LINES SHOW SECTION ON

PLATE VIII.
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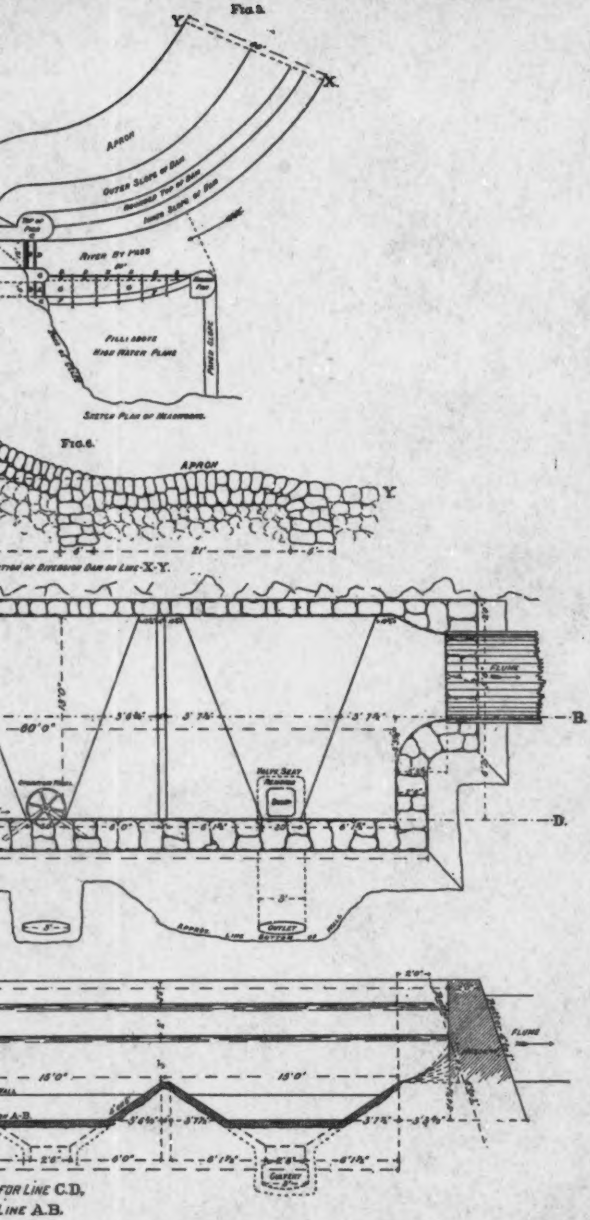
HALL ON SANTA ANA CANAL.



Diversion Dam, Sluiceways and Headworks.

The diversion dam, sluiceways and canal headworks, when finished, will constitute one construction, but for the purpose of keeping separate the cost of each of the important parts, they enter into the engineering accounts as three structures. Only the headworks proper have to this time been worked upon, and these are not completed. There being as yet no dam, water is brought to the heading by a temporary ditch from a favorable point of intake, for the comparatively small quantity now handled, 921 ft. higher up the stream.

For the purpose of making clear this location of diversion works and the relation and expected duty of the constructed part, it will not be out of place to submit a sketch and general description of them as planned, notwithstanding so little progress has been made in their building.

The location is dictated and design controlled by the torrential nature of the stream, whose waters, even at high stages—when rolling boulders and cobbles and whisking gravel and sand of all grades along with their flood—are to be diverted into an aqueduct which must, as far as possible, be kept free from such wearing and destroying detritus. For this work is to serve not alone for delivery of water during the irrigation season, but also for transportation of flood waters to storage reservoirs along its route.

The general ideas designed to be realized at the heading are : (1) to interpose, in the form of a dam, across the river cañon as little obstruction to the free flow of its high floods as possible ; (2) to keep the ordinary flood and low-water flow of the stream permanently in a channel next to the intake ; (3) to prevent the lodgment and accumulation of detritus either at or immediately above or below the intake ; (4) to draw the clearest available waters into the canal heading ; (5) to sluice the heavier detritus and more heavily laden waters rapidly by the same.

The plan (Fig. 5, Plate VIII) shows that the heading tunnel takes water from the end of a chamber or bay 60 ft. long and 12 ft. wide ; while this chamber receives water along and for nearly the full length of its side, from the river by-pass channel which lies parallel to and is separated from it by a thin partition of movable weir shutters running in upright iron guides. Taken together, the by-pass channel and the receiving chamber form a waterway 26 ft. wide on the bottom, and with parallel sides,

in curved plan, as shown ; while, splitting and diagonally crossing this waterway, lengthwise, is the partition holding the intake weir shutters. This waterway, held between the dam on the outside and the inner wall of the chamber, leads directly to two aqueducts—one, the canal, in tunnel through the solid rock ; the other, the escapeway, on solid rock and concrete, with an outer pier and wall of masonry. The headgate, the intake weirs and the sluice gate afford the means of regulating the water's flow, as may be desired, into the one or the other aqueduct.

The floor of this double waterway, from under the foot of the dam's slope to and under the foot of the chamber's sloping wall, and from the head and sluice gates to the upper limit of the structure, is a pavement of boulders set in cement on a concrete foundation. The dam's slope is of boulders in cement, and the chamber wall is of the same slope and construction. A heavy fender pier of masonry on a deep concrete base protects the upper and exposed corner of the chamber ; and from the side of this pier a sloping wall heavily paved with boulders in cement, footing on a concrete spiling wall, extends to the cliff, to cut off possible attack by extraordinary floods, in the rear. The space between the chamber wall, this fender pier, the storm wall and the cliff, is to be graded up with material blown off the cliff above and will serve as a site for keepers' house, etc.

A rolling drop of 1 ft. at the lower end of the chamber is made to facilitate entry to the headgate, and this same object is planned for in shaping the training walls each way from the gate itself. A drop of 2 ft. immediately below the sluice gate is intended to facilitate clearance of the bay above. The sluice gate, 14 ft. wide, is made of iron, trussed behind, to move on rollers and be operated by hydraulic power. The headgate is of similar construction. Both hold within their movable frames weir shutters which can be operated independently of the framed gates as a whole. A platform overhead affords space for operation. This rests on the solid rock each side of and over the headgate which is in the masonry arched portal of tunnel No. 1, and extends thence across to the masonry pier forming the outside abutment of the sluice gate. The iron guides of the intake shutters project well above the highest possible floods, and there serve as pillars to hold floor beams extending over the chamber from its inner wall. Suitably braced, this iron framework is designed to sustain the water pressure and shock on the weirs, and also to carry an operating platform overhead. The weir

shutters or flashboards are operated by a specially designed apparatus from this platform. They are set and run so that their outer faces are flush with those of the iron standards which hold them—thus presenting an unbroken plane to the waters in the by-pass channel.

The dam is level topped from end to end, rounded transversely, and planned to be not more than 3 ft. higher than the mean height of the boulder-bed of the cañon. Its rounded top and sloping sides, extending down into the boulder mass, are intended to present the least possible obstruction to the flow of the greater floods, which are expected to go over its full length and to fill the space above it with gravel and boulders, except in the river by-pass channel, where these will be carried through by force of the concentrated current.

The features to which attention is specially invited are (1) that of taking waters into the work from the surface of the natural flow, in a thin sheet over a long weir lip, and with the least possible deflection of their line of flow; and (2) that of under-flushing the waste or escape waters down a drop past the intake. These two features, the writer thinks, embody principles on which works should, whenever possible, be planned for diversion from natural streams into irrigation canals, but which are frequently violated, even reversed in application, in many important works in our country.

The objects are, of course, to take in water and keep out its sediments, sands and gravels. An underflow gate draws from the bottom of the stream, and, because of this, is the proper design for a sluiceway—to get rid of the sands and gravels carried near or rolled along the bottom. It should not be used for an intake, for, thus used, it directly defeats one of the primary objects desired. Overflow gates, usually put in as flashboards, can be designed so as to admit of handling with perfect ease under any circumstances. They draw from the top of the stream first; and heavier detritus has to accumulate above before passing over them. They are, for this reason, detrimental in a by-pass sluiceway, but exactly applicable for intake gateways; and, where the waters are carrying sediments, the intake should be in a thin sheet over such gates, so as to draw only from the surface of the natural stream.

The arrangement of the intake openings on the side of the headworks chamber, and not in a heading transverse to the run of the stream and canal; the placing of the gates flush with the outer faces

of the piers which hold them, and the introduction of light iron piers between the gate openings, are points of design offered in this work as novel in irrigation and engineering practice and at once cheap of construction for permanent work, and purposeful to the special ends in view. These are the securing of as long an intake lip as may be desired without affording either a bay or a recess for an eddy where detritus or sediment would accumulate above the gates; and the minimizing of obstruction to, and deflection of, the current in passing from the natural stream into the canal, and in the stream itself, past the heading.

The advantage and even necessity of observing these points in design for the work under description becomes the more appreciable when we reflect that the stream in flood will come to the heading with a mean velocity of about 8 to 10 ft. per second; that this rate of movement is to be maintained in the canal; that such a current cannot be passed around large obstructions without immense disturbance; that a head-bay which would effect the lowering of velocity at time of full intake, so that corners might be turned by the waters, would be subject to silting up at a period of low flow and would necessarily be far larger and more expensive.

The design and location specially admit of the works being raised—carried in all their parts higher—as, in course of time, the cañon-bed becomes filled to higher planes by the gravels and boulders which are brought by its floods.

For instance; it will be readily seen, from the section (Fig. 6, Plate VIII) that the dam can be raised as required by building over it successive layers of boulders, laid in cement. The piers of the headworks are planned to admit of raising indefinitely, and other parts are equally susceptible of raising or being built up without excessive cost or much change in other respects. The writer hopes at a future day to present an account of the completed construction and operation of these diversion works, and to submit the plans in detail.

Expenditure at Headworks.—The work done at this heading and its cost was substantially as follows :

First.—The distinctly temporary work. A diversion dam of cobbles, boulders and gravel—about 110 cu. yds. in volume ; a rough rubble heading work, holding a wooden gateway 5 x 5 ft. ; thence a semi-circular-formed ditch 7 ft. wide, and paved with boulders and

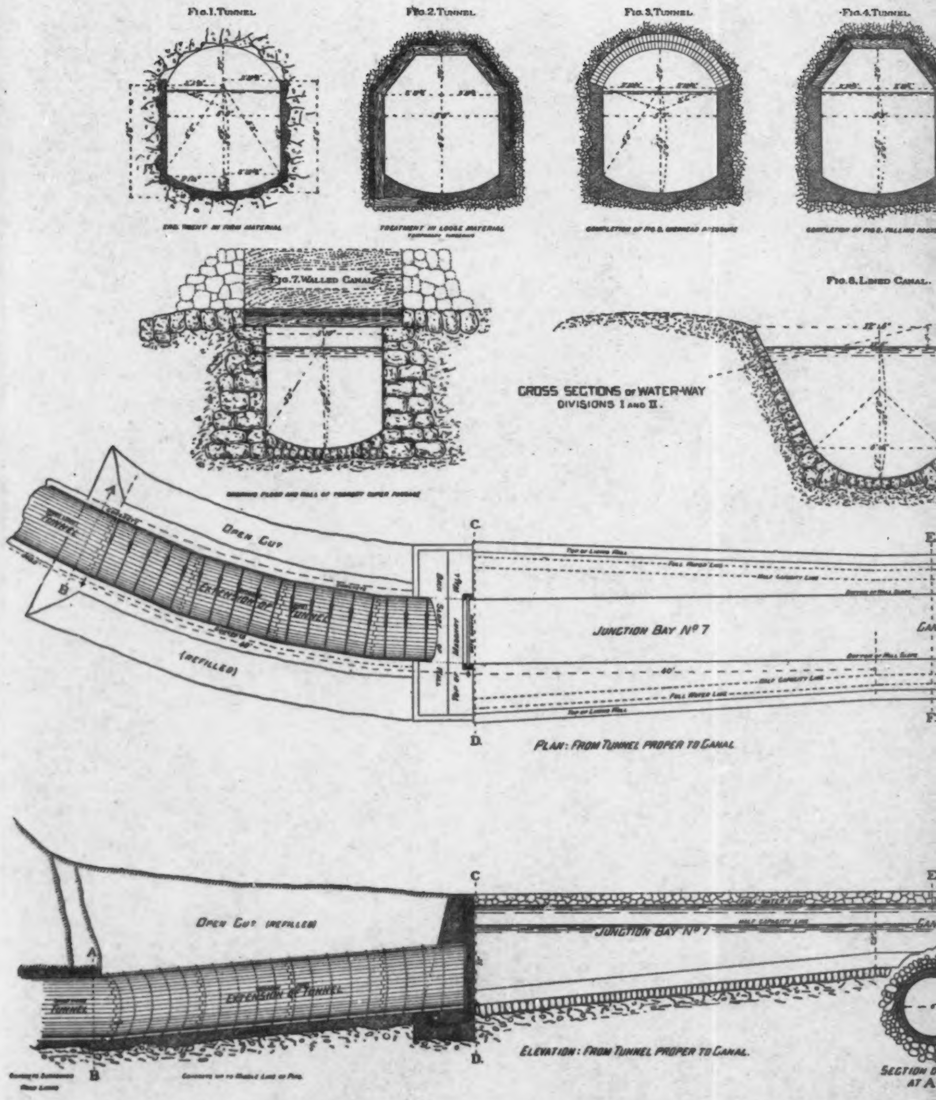


Fig. 1. Tunnel
Fig. 2. Tunnel
Fig. 3. Tunnel
Fig. 4. Tunnel
Treatment in Loose Material
Fig. 7. Walled Canal
Fig. 8. Lined Canal
CROSS SECTIONS OF WATER-WAY
DIVISIONS I AND II.
C
D.
E
F
A
B
Open Cut
Extension of Tunnel
(Refilled)
Junction Bay Nº 7
PLAN: FROM TUNNEL PROPER TO CANAL
Open Cut (Refilled)
Extension of Tunnel
Junction Bay Nº 7
ELEVATION: FROM TUNNEL PROPER TO CANAL.

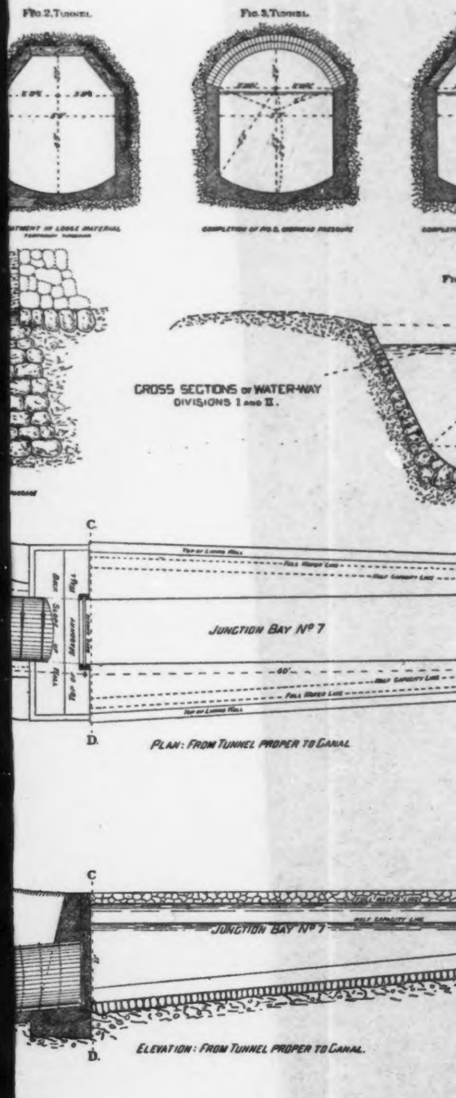


Fig. 2, Tunnel.
Fig. 3, Tunnel.
CROSS SECTIONS of WATER-WAY
DIVISIONS I and II.
C
JUNCTION BAY No 7
D.
PLAN: FROM TUNNEL PROPER TO CANAL
C
JUNCTION BAY No 7
D.
ELEVATION: FROM TUNNEL PROPER TO CANAL.

PLATE IX.
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FIG. 4. TUNNEL.

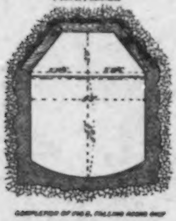


FIG. 5. TUNNEL.

FIG. 6. FLUME.

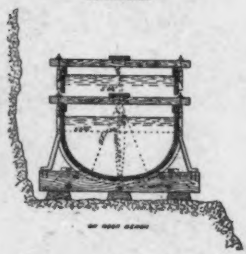


FIG. 8. LINED CANAL.

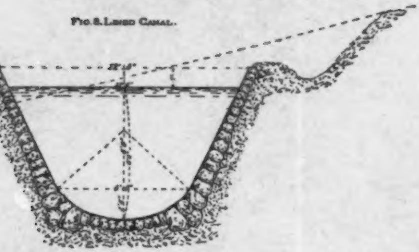
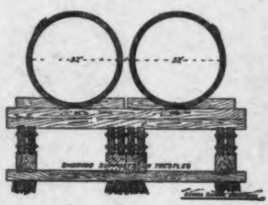
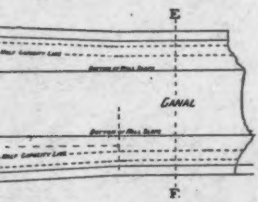


FIG. 9. PRESSURE PIPES.





PLAN AND SECTIONS
JUNCTION BAY No. 7
AND
EXTENSION OF WOOD-LINED TUNNEL
DIVISION II
FIG. 10.

cobbles and well chinked and sanded, 900 ft., to the site for the permanent heading, involving 380 cu. yds. of excavation, in gravel and boulders, 40 cu. yds. of embankment, 13 500 sq. ft. of paving, with the gates, dam and heading; cost, $752 08. The ditch proper, paved, cost $615, or 67.2 cents per linear foot.

Second.—Work on the permanent heading. Excavation for and laying of 270 cu. ft. of concrete as part of the foundation for the permanent work; 27.2 cu. yds. of masonry in cement, permanent intake, arched portal to tunnel No. 1, with training walls and abutments thereto, and foundations for outstanding gate piers; 280 sq. ft. boulder paving; 110 sq. ft. cement mortar plastering; headgate, and two wastegate frames in wood, and flashboards. Total cost, $399.37. Rates of cost of work are given elsewhere.

Tunnels.

Of the nine tunnels in division I, eight are through rock and were driven by contract, and the ninth is through cemented gravel and boulders, and was driven by day labor. The contract tunnels were let in one; though, to encourage tenders by men of small as well as those of large means, under the advertisement and specifications the award might have been made in five contracts, namely, one for each of the two long tunnels, and one for each of three groups of short tunnels. Eleven tunnels were originally advertised. Of these, four short ones were thrown out because of the shattered condition of the rock, as disclosed by excavating approaches, and open cuts were substituted; two others were united in one by a slight change of location, and two additional tunnels were brought under the contract by a subsequent agreement. Messrs. James J. Searle and J. P. M. Phillips, of San Francisco, were the contractors.

The lengths herein given for tunnel work paid for do not always correspond to the lengths of the finished tunnels as they appear in the structure schedule, because the finish work of the junctions or of the portals was not always coincident with the commencement or ending of the tunnel contract work. At the time the tunnel work was advertised the company was uncertain when it could commence grading the flume bench, and, hence, bids were asked for tunnel approach excavation, and the contract included this at a rate per cubic yard. It was expedient to commence the two long tunnels thus early, in order to

effect their driving and lining where necessary by the time it was hoped to have the balance of the work done—namely, before the company's water exchange contract with the Mill Creek zanja owners ran out. And thus the contractors' force was on the ground before the final location was finished over the route covering the tunnel sites.

Under the specifications the contractor was to do all the work, furnish all materials, tools and outfit required therefor, except what lumber might prove necessary for lagging and timbering. This the irrigation company was to furnish and deliver at the nearest point it could be wagoned to without constructing roads specially for the purpose. But little timbering was anticipated, and this expectation was very nearly realized.

All the tunnels were to be uniform in cross-section; but provision was made for such variation, in excavated section, as timbering would make necessary. The excavation to the neat line, through hard rock, not requiring timbering, was to be 6 ft. 3 ins. wide and 7 ft. 6 ins. high, inclusive of the arched top and invert, in the form shown by Fig. 1, Plate IX. These dimensions practically make necessary about 1.5 cu. yds. of excavation, as a minimum, to the linear foot of tunnel. Through material requiring timbering the form and dimensions were to be as shown by Fig. 2, and these necessitate about 1.9 cu. yds. of excavation per linear foot.

The specifications were explicit and stringent as to exercise of care not to unduly shatter materials driven through, because it was desired, wherever possible, to avoid timbering or otherwise supporting the roofs; and experience in California is to the point that tunnel contractors will "blow the hill to pieces" in order to cheapen their work, if they are not held in check. Moreover, seeing that the tunnels were certainly to be lined for the waterway, there was a penalty provided for excess of excavation behind the neat line, beyond a 6-in. average limit for any 10 ft. of tunnel, as well as for bad results, in sides or roof, due to excessive use of explosives. A principal feature of this penalty was a charge against the contractor of 40 cents per cubic foot of concrete which it would take to fill space worked out, or badly shattered, in excess of the limitation.

The specified time-limit, to cover all the tunnel work, was based on one day for each 12 ft. in length of the longest tunnel to be driven, with an additional 12 days for each approach to that tunnel. In the

PLATE X.
TRANS. AM. SOC. CIV. ENGRS.
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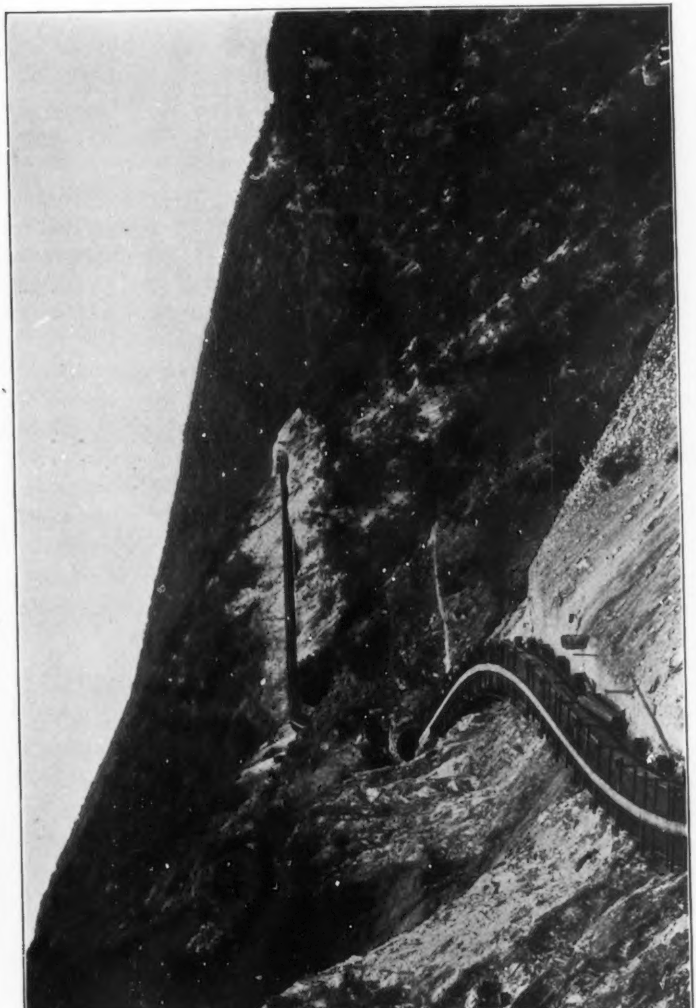
HALL ON SANTA ANA CANAL.



contract this limit was extended about 10 days and fixed for a definite date. Payments of 75% were to be made on progress estimated every two weeks, and the balance was to be paid 35 days after completion and acceptance of the work as a whole.

In consideration of all the work being awarded them, the contractors agreed to throw off $1 000 from the total amount which would in the end be due them. One hundred dollars per day was the penalty forfeiture for the time taken over the limit, to effect completion. As it turned out, this latter provision was not enforced, because the irrigation company itself was delinquent in making its payments, and the tunnels could not have been used had they been finished on time, seeing that other parts of the work were even in greater degree behind hand. The full completion was delayed more than a month, but the tunnels, severally, were ready soon enough for the company's occupation and finish work. That which took the longest time was not the longest tunnel. The longest, tunnel No. 8, was finished within the limit, but tunnel No. 5, which was 184 ft. or 15⅓ days shorter, took nearly two months longer. Fortunately, there was no necessity for either timbering or lining, for immediate use, any portion of the waterway of this tunnel No. 5, except at and very near the south portal, as there was of tunnel No. 8. Most of the tunnels were sublet, the main contractor agreeing to furnish the plant, and, generally, a certain amount of powder and fuse, and to do the blacksmithing, and put in and operate ventilating apparatus where necessary, and the subcontractors doing the driving and all else.

The circumstance of letting by contract in with the tunnels the excavation of approaches thereto, and at the high rate of $1 75 per cubic yard, was unfortunate, not only as having materially increased the total cost by reason of the excess of this rate over what the work could have been done for by the day, in connection with the flume-bench grading, but as resulting in complication of the construction cost accounts.

For instance, four short tunnels let in the contract were abandoned and open cuts substituted for them, after more or less work had been done on their approaches. Could the engineers have had the advantage of working a day force for a couple of weeks prior to drawing the specifications in examining the points which these tunnels were expected to pierce, they would not have been projected, and the neces-

sity would never have arisen for crediting the tunnel account and debiting the flume-bench account with the amounts due the tunnel contractor for approach work to them, and for making certain other adjustments to get at the flume-bench cost.

On a work of this character, where a tunnel is in rock sufficiently hard to stand without roof support, and not subject to weathering, and if the face is well cleared and stripped above the opening, in the climate of Southern California portal walls and arches of masonry or other expensive construction can usually be omitted, and especially for tunnels through points where no surface-water channel comes down over them. The ends of nearly all of the tunnels in division I, Santa Ana Canal, were thus favorably situated.

In such cases the connection between flume and tunnel was made by carrying the former about 18 ins. to 2 ft. inside the solid tunnel mouth, opened out to leave a space 6 ins. to 1 ft. all around the flume shell, and then ramming concrete into this space, as elsewhere explained. Simple joinings of this class were charged against the tunnel account as "connections."

In cases where special portal work was necessary as finish to full lining and arched roof work, or to support the tunnel face, such work was charged against the tunnel as its portal. But where masonry tunnel portals were built as part of other constructions having a function separate from the tunnel, and where the masonry frontage was not necessary for the tunnel as such, the portal work was charged to the other structure. This was the case at the upper ends of tunnels Nos. 3, 4 and 6, at each of which points a masonry wasteway bay is located. These tunnel portals were built as gateways, to be closed when water is turned out of the wasteways immediately above; the flume connections were made at the other ends of the wasteway bays and as parts of those structures. At each end of tunnel No. 8 are special pipe junction bays, built with and including the tunnel portals, so there are no connections or portal charges, as such, here. At the intake of tunnel No. 1, the portal is counted as part of the headworks of the canal, and at its lower end all, except a small amount of work to protect from overhead débris, was charged to the walled canal which there makes close connection with the tunnel mouth.

As tending the better to adjust costs to what they ought to be, the $1 000 rebate to be taken from the total of the tunnel contract work has

been applied by the writer wholly in reducing the cost of the approach work, *pro rata*, wherever executed, and this adjustment reduced the cost of such work from $1 75 to $1 41 per cubic yard.

On Plate IX, Fig. 1 shows the form and dimensions of excavation and lining with concrete adopted for tunnels in hard rock, which would not for any reason require overhead timbering and arching, and which would have to be lined for purposes of the waterway only.

Fig. 2 shows, in section, the form, dimensions, temporary timbering and subsequent concrete finish for bottom and sides adopted for tunnels in ground requiring full timbering and lagging as driven. This section was intended to be finished for permanent work, as might be expedient in conformity with one or the other of the two following. According to circumstances, also, it was expected that the space behind the lagging, and consequent thickness of final finish of this section, would vary much, and such has proved to be the fact. The drawing shows the very minimum space and thickness possible.

Fig. 3 shows the section, dimensions and finish adopted for tunnels in rock which would stand without timbering at first, but which would require lining to support the walls, and in whose roofs some settlement and pressure might be anticipated. According to circumstances, the concrete walls might be somewhat lighter, and under others they were expected to be somewhat heavier than shown. The brick arch of this section, backed with concrete, is intended also for application in the final finish of section II in cases where roof pressure might be expected.

Fig. 4 shows the form and dimensions and roof finish adopted for tunnel in material that would not require timbering as driven, but would require subsequent lining for wall support and to prevent droppings from the roof, due to air slaking. The remark made about thickness of walls for section III applies equally to this one. This section, IV, was proposed as a substitute for section III, where allowable, for the period of the life of one roofing, at least, because much cheaper. As will be observed, the roof in section II is lower than in sections III and IV. This was thus purposely designed, to admit of trimming in putting in final work.

The quantity of concrete required for any of these linings depended, of course, very much on the extent to which excavation was actually carried. Except where more work might be necessary to preserve the tunnel, it was the intention at first to bring the permanent lining only

so high on the sides as would afford waterway for the half-capacity finish elsewhere spoken of. But in tunnel No. 8, for want of time and means, the concrete finish was not brought even to that height, as will be shown.

Tunnel No. 1.—Length, 216 ft.; a medium hard rock of granitic appearance, but not a true granite, disposed in heavy strata, dipping about 45° and with a diagonal strike across line of work; occasional seams less than 1 ft. thick, of much softer material, and with more the appearance of granite, subject to air slaking and certainly liable to erosion by strong water currents and disintegration therein; occasional very hard spots and nodules, making uneven and hard drilling, worked out irregularly in blocks and masses; difficulty in holding excavation, within limits, to lines and grade; no water encountered; no timbering necessary, except temporary at south portal; some material, especially near bottom, too soft to trust water on; hence, necessary to put in lining before using, although most of the material would stand water indefinitely.

Cost.—The contract price for driving this tunnel was $9 per linear foot; or, total cost, $1 944. From this amount $36 was deducted as a penalty for 90 cu. ft. of excessive excavation, thus reducing the amount paid to $1 908, or $8 83 per foot. Adding $60 12 expended in day labor trimming and final clearing preparatory to actual lining work, and the total cost to the company, before lining, was $1 968 12, or $9 11 per linear foot. The work was understood to have been sublet at $6 50 per linear foot, the main contractor, in addition, supplying tools and doing the blacksmithing. But, owing to slow progress on part of the subcontractor, the main contractors took it out of his hands and finished it under pressure for time, and, as they claim, without profit.

The waterway is completely lined with concrete, as per Fig. 1, Plate IX, at a total cost of $637 70, or $2 95 per linear foot. Total cost of tunnel, $2 605 82; $12 60 per foot. As already explained, there were no portal or connection charges against this tunnel. Details of cost are given elsewhere.

Tunnel No. 2.—Length, 208 ft.; a medium hard granitic rock, much like a true granite, but with many cleavage planes; no distinct stratification; occasional hard nodules and masses; some soft and apparently disintegrating layers, subject to air slaking, and, in a small degree, liable to erosion and disintegrating action of water; a few seams

which may extend and cause leakage; worked out in small masses; no difficulty in keeping within limit to line and grade; no water encountered; no timbering required; not necessary to line for immediate use; will require lining before more than one-fourth capacity is taken through, and within a couple of years; contract price, $8 50; supposed to have been sublet for about $6 50 per linear foot.

This tunnel was virtually a gallery driven 10 to 20 ft. within the cliff's face. At one point where there was a deep gash in the precipice, about 8 ft. in length of side was blown out and a slide came down from overhead. Repairing this, about 7.5 cu. yds. of masonry wall, together with some concrete and plaster work, and a roofing protection of timbers, was put in. There was no lining work done in this tunnel except just enough to well connect its waterway at each end with the flumes section. There was no work distinctly in the nature of portal masonry.

Cost.—The cost of driving, with $5 50 for clearing and trimming and cleaning, brought the total cost of tunnel to $1 773 50; per foot, $8 52. Flume connections, $16; wall, overhead protection, etc., $87 18, with some concrete used in lining and work at portals, brought total to $1 896 68, or $9 11 per linear foot.

Tunnel No. 3.—Length, 236 ft.; practically the same materials and conditions as tunnel No. 2, but somewhat more homogeneous; contract price, $8 75; supposed to have been sublet at between $6 and $7 per linear foot.

Cost.—This tunnel was not lined, but some patchwork was done with concrete and plaster to stop seams which might leak and waste water. A dry rock wall was built at one of the portals at a cost of $42, which with one of the flume connections, $8 50, the concrete patchwork and the usual amount of lining to join the flume waterway, brought the total cost to $2 144 53, or $9 09 per linear foot. Of this, $2 070 was for driving and clearance, $8 77 per linear foot. The cost of work and flume connection at the north portal of this tunnel was charged to wasteway No. 2, there located.

Tunnel No. 4.—Length, 54 ft.; moderately soft but firm and uniform; very near a true granite; not in layers; evidently subject to air slaking; probably but little subject to action of water currents; worked out very regularly and true to lines and grades; no water encountered; no timbering necessary; no necessity for lining for im-

mediate use, but will have to be lined within a year or two, before exposure to air takes effect; contract price, $8 75; supposed to have been sublet at $6 per linear foot.

Except as a preservation from air slaking there would be no necessity for lining this tunnel with concrete. It cut out quite smooth and true. If the work had been on force account the section might have been diminished and a heavy plaster finish applied directly on the face of the rock. A masonry portal and gate at upper end of this tunnel is part of and charged to wasteway No. 3, next above it.

Cost.—Driving, $472 50; with clearance, $2 30; flume connections, $7 80; work about portal, $11, brought the total to $494 11; $9 15 per foot, as completed for present use; $8 79 as driven and cleared.

Tunnel No. 5.—Length, 1 410 ft. A dark, close-grained solid granite; very refractory to drill and hard to blast; worked out in large masses, very irregularly, leaving a rough and uneven face all around; much difficulty in holding excavation within limit to lines and grade; water encountered in both headings, and drips from overhead gave much trouble; no timbering necessary, except at south portal, where is a slide from mountain overhead; no necessity for lining for preservation, except at locality above mentioned; contract price, $9 74; supposed to have been sublet at about $6 50; subcontractor forfeited contract; main contractor finished work.

The rock was hardest near the south end, where the average daily progress was 3.2 ft. against 4.7 ft. for the north end face, a total average of 7.9 ft. per day. Steam drills tried in the south face, but heat from exhaust and difficulty of carrying steam so far with the plant at hand rendered them impracticable. Ventilation at first effected by stove draft, then hand blowers, and then steam-power blowers. Portals both in deep ravines; hence, less circulation of air about portals and more necessity for artificial ventilation in tunnel.

Cost.—Driving contract, $13 733 40, less $39 for insufficient trimming, and $433 90 penalty for excessive excavation; balance, $13 260 50; $9 40 per linear foot. The amount actually expended in force work for clearance did not materially change this rate. Some timbering and concrete lining was put in at the south end at a total cost of $195 43, which, with brick, etc., portal work at same end, $40, and flume connections, $18, brought total to $13 532 43, or $9 59$\frac{7}{10}$ per running foot.

Tunnel No. 6.—Length, 58 ft. A soft, shattered shale in strata, dipping across line of work; worked out irregularly; difficulty in keeping within limits to line and grade; no water encountered; overhead timbering not immediately necessary to prevent effect of air slaking; contract price, \$8 75; supposed to have been sublet; rate unknown.

This tunnel was lined with concrete to the height for full capacity, and cement plastered, as in the case of tunnel No. 1. The cost of driving, under the contract was \$507 50; as cleared ready for lining, \$517 50, \$8 92 per linear foot; lining, \$270 50, \$4 66 per linear foot; portal work, additional, \$15; flume connection, additional, \$5; total \$807 65; \$13 92 per linear foot. It may be necessary to timber and lag this tunnel overhead in future, to prevent rocks dropping, consequent upon air slaking. But one portal finish and one flume connection was charged to this tunnel, the other being charged to the wasteway there adjoining it in the line, and as part of which it was designed and built.

Tunnel No. 7.—Length, 43 ft. A soft, shattered shale in strata, dipping across line of work; worked out irregularly; difficulty in keeping to lines and grades; no water encountered; timbering necessary in places; lining and arching immediately necessary for every good reason; contract price, \$8 75; supposed to have been sublet; rate unknown.

This tunnel was lined completely, as illustrated by Fig. 3, Plate IX. Concrete invert and walls to the full-water finish; a brick in cement arch overhead, and the whole finished in cement plaster. The portals were simply finished in brickwork (see Fig. 1, Plate XI).

Cost.—Driving, \$376 25, and clearance, \$19—\$395 25—\$9 19 per foot; lining, \$437 94, \$10 18 per linear foot; portal finish, additional, \$30; connection, \$10; dry masonry walls, \$71 75; total, \$944 94; \$21 94 per linear foot, the most expensive part of the entire aqueduct. This high cost is very largely due to the inconvenience of subdelivery to the site of the work, and to the large proportion of labor waste at the time construction was here in progress.

Tunnel No. 8.—Length, 1 594 ft.; south end, 700 ft., in soft marly shale, requiring timbering; occasional seams bearing water, causing sliding ground and rock caving, and necessitating close and immediate lagging; some serious trouble from this cause. Balance of tunnel in soft granitic rock, but apparently not true granite; some liability to

air slaking and washing by water; worked out much more regularly than the south 700 ft.; timbering not necessary. Immediate lining necessary throughout, as high as water is to be carried. Contract price, $9 74 per linear foot; supposed to have been sublet at $6 per linear foot.

The conditions for working this were, on the whole, favorable for so long a tunnel, notwithstanding the difficulty had with water and the trouble of timbering. The average daily progress was 6 ft. in the north end heading, and 7 ft. in the south end. Ventilation was effected by stove drafts only, as both ends of tunnel open into big cañons where there was free circulation of air past the portals.

The timbering was done for the 700 ft. in accordance with the plan shown in section by Fig. 2, Plate IX. The concrete lining was put in for the invert and walls 1 ft. high, and plastered, in accordance with the same plan.

Cost.—Driving, contract, $15 525 56; clearing and trimming during course of lining, force, $119 87; total excavation, $15 645 43. Lining, total, $3 131 38; including concrete, $2 317 78; plaster, $467 60; tile drainage, $36; cost and delivery of timber and lagging lumber used in driving, $310. Rates per foot of tunnel: driving and trimming, $9 13; lining, total, $1 95; concrete, $1 45; plaster, 29 cents; concrete and plaster, $1 74.

Tunnel No. 9.—Tunnel No. 9, through Morton Ridge, 509.8 ft., is in a mass of cemented boulders and gravel. Firm and generally very hard when first bored, this material is subject to slow air slaking as well as to more rapid disintegration under the influence of water and the moisture over it in a tunnel. Farther on in the general route of the projected canal, a number of narrow, sharp, but long ridges—saw-tooth spurs of the San Timoteo range of hills, similar in general formation to Morton Ridge, but whose substance is much more easily pierced in tunneling—are encountered. If an efficient and durable lining can be put into such tunnels within a certain low limit of cost, considering the very cheap rate at which the ridges in question can by special means be pierced, there would be good reasons for adopting a location whereon, in construction, this character of work would be given prominence. The lining of tunnel No. 9 was intended, therefore, not as a novelty and study of economy for that one bore alone, but as an experience, the results of which might govern the placing and building of several miles of the line beyond.

FIG. 1.

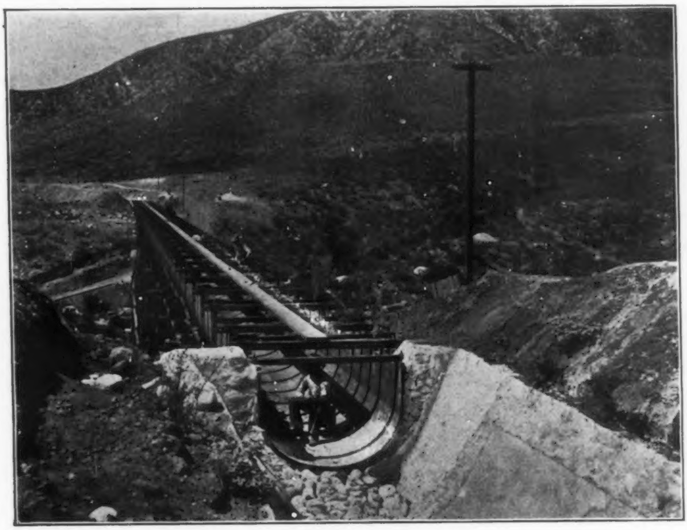


FIG. 2.

Brick and cement concrete linings in any form of cross-section, but sufficiently thick to insure against dropping of large boulders or masses of the cemented gravel which are liable to become detached in this peculiar formation, would be too expensive for the work. Experience on this company's older works has also shown that asphalt or asphalt concrete cannot be depended on under these circumstances as a tunnel lining when put in thin enough to make any material saving in cost under that of cement concrete or of brick. The ordinary wood linings of tunnels would very soon rot out. It appears that something new as a lining had to be evolved, or the idea of location through the sawtooth spurs be given up, if another advantageous route could be found.

As completed, tunnel No. 9 is a smooth-finished tube, 6 ft. inside diameter. The lining is made of 3-in. thick redwood staves, which have been firmly pressed into place and are solidly held within a thin shell formed by ramming concrete as a backing into the space between the staves and the face of the tunnel bore. It is in effect a wooden stave pipe, not banded with metal, but held just as tightly, for all practical purposes where there is scarcely any head of water pressure, by being pressed in concrete through the solid hill. The wood and concrete lining thus formed is more than amply strong to withstand any pressure from without that will be brought upon it in Morton Ridge or any similar location. Properly put in, it will not leak ; so there will be no danger from the effect of wetting the material through which it is laid. And to preserve the wood, tunnel No. 9 is located more than its diameter below grade, so that, no matter how little water may be running in the aqueduct, the tunnel must remain full and the staves be always thoroughly soaked.

Although, owing to reasons elsewhere explained, the cost of this tunnel as a whole was not low, the experience has shown the feasibility and advantage of lining tunnels through material having the general character of cemented gravel, marl, compact earth, soft but firm stone, etc., by the general method here experimented with, and at costs so low as to command attention for works of this class. And it is believed that the location of such tunnels so that they will always be full of water and under very light hydrostatic pressure establishes conditions such that the wooden lining will last as well as any other, within practicable limits of cost for irrigation works.

There was nothing novel in the excavation of tunnel No. 9, and the means for making such bores in softer materials, which the experience suggested and showed the feasibility and desirability of, will properly find description only after more extended application.

The lining was put in as follows: The concrete backing for about one-sixth of the circumference was first laid in the bottom of the tunnel bore and rammed to grade and form for a considerable length in advance of other work. In a layer of wet mortar spread over this bed staves were laid, and on top of them the tunnel-centering forms were set. These bottom staves were then clamped together, and, at the same time, the tunnel forms forced down on them. When these bottom staves for several lengths were thus brought to their position and bearings, and the forms centered and tightly braced in position over and upon them, the lining was laid up around the sides. One stave at a time, on the two sides simultaneously, was placed and firmly pressed and clamped into bearing against the next stave below it and against the outside of the centering frames, and immediately the concrete was shoveled and rammed into the space behind it. Thus the lining was brought up and around until it came to placing the last three staves overhead. Two of these, one on each side—in form tapering lengthwise, so as to leave remaining open between them a space, and tapering several inches in the length of the stave—were then placed. After concrete had been tamped over these last staves on each side, the opening between them was closed by driving endways into it pieces of stave, each 1 ft. long, and duly tapering, over each of which the concrete was rammed, longitudinally, before the next one was driven.

This lining was built in lengths from 8 to 14 ft. each, as the lumber ran. The staves of the succeeding lengths were "broken-jointed" together, with an end lap of 4 ins., and the end joints were made, between each two abutting staves, with a metal tongue taken into a saw kerf in the staves' ends, as in recent wooden pipe construction practice. The staves were a little less than 8 ins. wide, somewhat less than 3 ins. thick, with the edges milled to radial lines of the circle in which built, and with a $\frac{1}{8}$-in. bead on each edge, one-third the thickness from one side.

The tunnel is straight for 400 ft. of length; then it curves to the left for 69.8 ft., on a radius of 91.7 ft.; and thence the wooden shell

was built as a banded pipe in an open cut, and in continuation of the curve for 40 ft. further, where it ends in a concrete portal wall. The space in the cut around and over the built pipe having been refilled and made solid, the whole has a uniform tunnel-like effect.

By referring to the plates the application of the following about some details of this tunnel work will be made clearer. Plate IX, Fig. 10, explains the relation of the parts to each other and to the hydraulic grade, at the tunnel's lower end. Figures on Plate VIII relate to the arrangement at the upper end.

The down-stream end of the tunnel proper—469.8 ft. from its intake—is 80 ft. from the point of commencement in normal section and on grade of the lined canal, and is 7 ft. below it in grade elevation. The grade plane between these two points rises evenly—that is, 7 ft. in 80, or at the rate of 8.75 per cent. Of this distance, 40 ft. is the tunnel extension, made in open cut and afterwards covered in as above explained, and 40 ft. is constructed as a backwards extension of the lined canal—widening on top as due to side slope, and deepening on the 8.75% grade—to a junction with the tunnel portal wall.

In the opposite direction, from its down-stream end, the tunnel proper falls 2 ft., so that at its up-stream end its grade plane is 9 ft. below that of the commencement of the lined canal, 549.8 ft. down the line from it. Thus the entire tunnel proper will be under a pressure head of between 1 and 3 ft. at its top plane when there is any water whatever running in the aqueduct, and between 7.3 and 9.3 ft. when the full 240 second-feet are flowing, besides the additional head which its own hydraulic gradient will subject it to.

At its up-stream end it flares, in 16 ft. of length, to an oval having horizontal and vertical axes of 114 and 72 ins., respectively. The purpose of this flare was to receive, with least disturbance of current, the waters from two 52-in. pressure pipes, laid side by side, and 6 ins. apart, and which will form the completed aqueduct across Morton Cañon. This junction is referred to more in detail elsewhere. Thus, the Morton Ridge tunnel is, in effect, a continuation of the Morton Cañon pressure pipes united.

Provision is made by a gateway at the down-stream portal of the tunnel to close it, from below up, sufficiently to keep the wood lining of the down-stream extension, where it rises above canal bottom grade, always submerged, no matter how little water be running in the

aqueduct, if so desired. And at the up-stream end provision is made for emptying it backward into Morton Cañon for the annual clearance.

The up-stream oval flare was built the same as the cylindrical lining, inside of its excavation, made to due form and dimensions. Staves were tapered to suit; pressed into place, one by one, on each side; backed up with concrete, rammed behind each as placed, and the closure was made overhead with a taper stave, cut into 2-ft. lengths, and driven as wedges, successively, after concrete had been rammed lengthways, over each preceding one. The penstock making the junction between the pipes' ends and the flared tunnel mouth, and occupying 4 ft. in clear length in the line, sets close against the tunnel portal, receiving the tunnel lining staves in one side and the pipe staves in the opposite side, in the relative position shown by the figures on Plate VIII, Fig. 4.

In making the curve and breaks in grade at the south end of the tunnel proper and in the open-cut part of the work, 10-ft. staves were uniformly used and sawed to allow for curvature angle in each 10-ft. bent or length, the longest stave in each length, on the outside of the curve, being 10 ft., and the balance shorter in due sequence; but the end joints were all made just as in the tunnel proper. In the open cut there were four $\frac{5}{8}$-in. round steel bands put on each 10-ft. length, as built in place, just to hold it tightly in form as a pipe, until the concrete could be rammed against it and the back filling be made after this latter had set. This part of the wood lining had a thicker bedding of concrete, and this bedding was brought up nearly to the half-depth line on each side.

About the first 50 feet of this tunnel lining was not put in to the writer's satisfaction. It was feared that some leak might develop that would in time soften the ground around it, so all the seams of this piece were opened with a spreading iron and calked with oakum, as were those also of the oval flare piece. And wherever, by thorough search throughout the entire work, a bit of seam could be found that did not appear by trial with a thin knife edge to be under pressure, it, too, was spread open and calked.

But the writer does not now think that this precaution was really necessary. These staves were quite well seasoned when put in, and their swelling would much more than have closed any open seam that

was found. Moreover, the cement paste of the concrete, by the process of ramming, was forced into the back part of seams where at all open, and this alone would insure a water-tight structure, even though the concrete itself might happen at some point to be specially thin immediately outside of a poorly laid portion of the stave lining. When completed, this tunnel had a most favorable appearance as a water conduit, and has since done good service without apparent leakage, except immediately at the penstock junction, for a short time at first; but this was soon stopped.

Several specially arranged steel centering frames and appliances for, and methods of, pressing and holding the staves into place were devised and used during the course of the work. The writer hopes to present this particular part of the subject at some future time more worthily than he can at present.

With proper appliances, and with due system in the work and close engineering supervision on the part of some one looking to the best outcome, the writer believes that most excellent results are to be had, and great savings effected, by this method of tunnel lining for water carriage through materials such as have been herein spoken of.

It is, in effect, lining a tunnel with a thin layer of concrete rammed behind mould boards, and then leaving the mould boards in place as part of the lining. In this connection, attention is asked to the following points: That to line a tunnel with concrete at all the labor of handling the centers and mould boards into place has to be performed, at any rate; that when this work is systematized and performed with special labor and time-saving appliances it can be materially diminished in cost and a far better job be effected; that in this manner the mould boards can be put in to stay with no more labor than for the ordinary temporary purpose; that if we leave the mould boards in we save the expense of handling them out; that the lumber part of the lining thus placed will generally cost, at the tunnel mouth, less per unit of volume than the concrete part; that it can be taken in and put into the work at less cost per unit of volume than can the concrete; that concrete is the cheapest efficient lining heretofore used (in Southern California, at least) for similar purposes; that this wooden in-lining seems to correct the defects and failings of thin concrete linings such as have here been attempted in tunnels for similar purposes, and to better guard against rupture by earthquakes; that the planed wooden

face diminishes friction, and materially increases capacity. Then, if the wood is not to decay, and if the lining is not to be crushed, it would seem that the device and method have advantages which make them worthy of attention.

It must be remembered, however, that this tunnel lining is spoken of only for the purpose of water carriage, and for localities where there is to be no ground movement, and, consequently, no great pressure brought upon it; because in such localities it can be put in very thin and very rapidly and very cheaply. Where it is continuously kept submerged—wood between cement and water—it would seem that a long life awaits it. Will not wood under these conditions outlast that in a pipe covered in earth? Is not the thorough coating of cement it receives on its outside, from the effect of ramming the surrounding concrete, and the casing of concrete itself, a preservative against the earth influence which is sure to shorten the lives of wooden pipes laid under ground, at least in many soils? As to the lasting qualities of such tunnel linings against the wear of sands, the same remarks apply as are elsewhere offered on this point with respect to pipes.

Cost.—The 469.8 ft. of tunnel proper cost \$5 939 27; of which \$2 129 75 was for driving and trimming, \$1 798 85 for concrete backing, and \$2 010 67 for wood lining; or, \$3 809 52 for lining complete. Rates per foot of tunnel: For driving and trimming, \$4 53; for the concrete backing, \$3 82; for the wood lining, \$4 28; for lining complete, \$8 11; for the tunnel complete, \$12 64.

The 40 ft. of extension cost \$353 80; of which \$103 was for excavation and back fill, \$60 50 for concrete, \$190 30 for the wooden pipes, banded, or \$250 80 total for the pipe and concrete setting. Rates per foot of extension: For excavation and back fill, \$2 57; for the concrete, \$1 51; for the wooden pipe, \$4 76; for the pipe and setting, \$6 27; for the extension complete, \$8 84. The tunnel and extension, 509.8 ft. in length, cost \$6 293 07—average of \$12 34 per foot of line covered.

Walled Canal.

The piece of walled canal next in the aqueduct to tunnel No. 1, shown in section by Fig. 7, Plate IX, is 152 ft. long. Of the total length, 60 ft. in the clear are covered with two layers of 2-in. redwood plank for the torrent superpassage, as illustrated by the figure above

referred to; and masonry walls, from the point of rock on either side of the ravine, serve as training walls to the torrent to and across the passage.

These walls, as also those of the canal itself, are built of heavy river-wash granite boulders, well bedded and laid in lime mortar with some cement. The canal invert was paved, chinked, sanded and grouted as hereinafter described for the bottom of the lined canal. And the entire inside of the waterway and tops of the walls were plastered with cement mortar. This plaster for the invert was the same as elsewhere described for such bottom finish; for the sides and caps of the walls it was 1 to 4 of cement and sand.

Cost.—In addition to 171 cu. yds. of sand, gravel and rock in the approach to tunnel No. 1, which was taken out under the tunnel contract at a cost of $241 11, or, $1 41 per cubic yard, but is herein charged to this piece of canal, there were moved for it by day labor 305 cu. yds. of sand, gravel and débris at a cost of $64, or 21 cents per cubic yard. Of this material, 110 cu. yds. were afterwards back filled and shaped into place against the walls at a cost of $12 10, or 12 cents per cubic yard; and 23 cu. yds. of heavy river boulders were hauled and placed for the paving of the superpassage channel, at a cost of $25 53, or $1 11 per cubic yard.

The masonry, laid in lime and cement mortar, measured 158 cu. yds., and cost $713 87, or $4 52 per cubic yard; the canal paving, sanding, etc., cost $22 90 for the 905 sq. ft., or 2.5 cents per square foot; 2 130 sq. ft. of cement mortar plaster were put on at a cost of $96 50, or 4.5 cents per square foot; and 20 cu. ft. of concrete, at the flume junction, cost $6 72, or 33.5 cents per cubic foot. These charges, with the cost of the woodwork of the superpassage channel, $63 50, brought the total cost of this structure to $1 246 23, of which $1 005 12 was originally charged to it, and $241 11 has been transferred from the tunnel account. This structure, like tunnel No. 1, is complete for the full duty of passing 240 second-feet of water.

The Flumes.

The flumes placed in these works are believed to be entirely novel in design and are thought to constitute a new type and departure in flume building. They are broadly described by the general name given—the stave and binder combination flume—and, substantially,

consist of wooden staves bound and held together in a rounded bottom, straight-side form, by iron and steel ribs and binding rods, acting in conjunction with wooden yokes or ties across the top.

In its simplest form this kind of flume is semi-circular in cross-section, and consists of staves drawn tightly together in that shape and held by binding rods bent to the transverse curve of the bottom, each serving to draw down on the top edges of the upper staves a cross-head or yoke which extends over the top, projects over the sides, and is engaged by the rods. In this primary form, with the staves milled in cross-section to the circle of the desired size—that is, with the outer side rounded to the circumference, and the edges beveled to the radial lines—it is plain that the edgeways compression of the staves not only serves to close the seams and thus render the shell water-tight, but tends to hold it in shape, out against the rods. With the top edges braced apart by the stiff yoke or cross-head, there can be no tendency for this shell to buckle inwards. It is essentially half of a wooden pipe.

Going a step further in the development of this flume, the sides, formed of broader boards, are carried vertically—in the line of the tangents from the ends of the bottom half-circle—to the height desired, and the yokes are put across, over the tops of the side boards, and the binding rods carried up to them. Then, applying the binding compression edgeways on the shell, at the top of the side boards, produces a tendency for these to buckle inwards; and, moreover, unless the shell is of small size, or staves proportionally thick, the whole structure would lack necessary stiffness and stability. To remedy this, stiff ribs, made also to serve as binders, are introduced at intervals in the length of the structure; and out to these the side boards are firmly held by a special device, which prevents their inward buckling or warping, while at the same time they and the staves are permitted to move edgeways around within the ribs, so as to admit of the necessary binding or loosening of the shell. Thus, the leading general idea is to have a flume shell compressible and adjustable at will within a framework, in order that it may be kept water-tight under all conditions and circumstances.*

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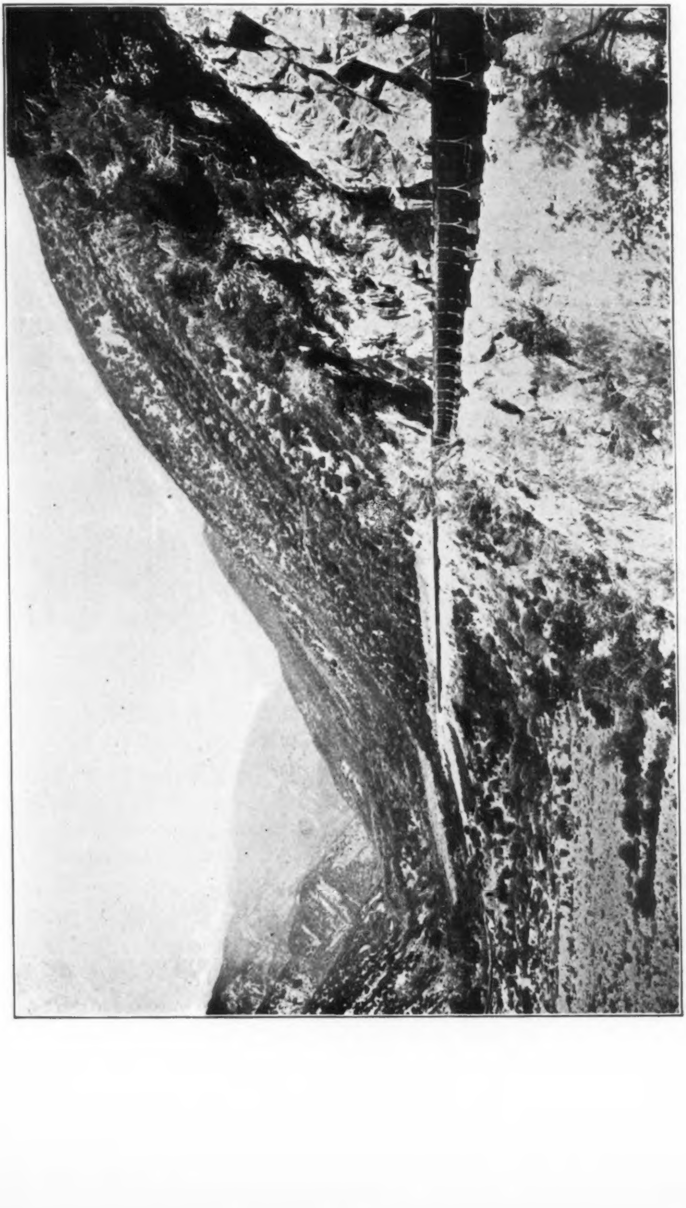
* This flume, in its primary form, was separately and independently invented by Guy Sterling, C. E., of North Yakima, Wash., and by the writer. The designs for the Santa Ana work are all the independent and original productions of the writer.



Different forms which may be given a flume of this character, and variations in construction details, will suggest themselves to the engineer. This paper presents the experience with the constructed examples of the Santa Ana Canal only. In section, these flumes have an oval bottom and vertical sides; are $5\frac{1}{2}$ ft. wide inside; and, as designed for full completion, are $5\frac{1}{2}$ ft. deep below the top of the side boards, and are intended to carry 5 ft. depth of water. The exceptions to these general dimensions are in flumes of division II, which, for reasons given, are planned an additional foot in depth.

The oval was adopted for the bottom form in preference to the half circle merely to give a flatter and broader seat to the ribs in the bolsters or sills. Considering the additional trouble and labor in manufacture and erection due to the oval over that which would have been given by the half-circle bottom form, it is doubtful whether there was a net advantage gained. For a very materially wider flume shell, say, 20 ft., it is plain that, in order to attain an economical proportioning of the waterway, secure a good seating, limit the expense of bolstering and bracing, and keep down expense of framing, the oval or even a flat bottom form (with rounded corners and straight sides) would be desirable. Or, on the other hand, for a materially narrower flume, say, 3 ft. wide, the semi-circular bottom would, unquestionably, be the simplest and the best.

Referring to Plate XIII, it will be seen that the Santa Ana Canal flumes have a stiff T-iron rib, resting in a wooden bolster or sill every 8 ft., and that between each pair of these ribs are two binding rods, thus making a binder every $2\frac{2}{3}$ ft. of length. As finished for present use, the sides in division I are but one board and a cap-piece high, making the waterway 3.8 ft. in depth below the top of the shell. It is intended to carry about 3 ft. depth of water, which on the grades adopted gives a present capacity of 120 second-feet. Raising the sides 2 ft. will double the capacity. The design eminently admits of such initial economy in construction and subsequent enlargement to meet full demand.

The binding rods are of $\frac{5}{8}$-in. round mild steel, screw-threaded (without having the ends upset) for 4 ins. at each end. It would have been better practice to use somewhat lighter steel, and to have had the ends upset before threading. The hurry in which these matters were determined and the desire to simplify the work for Cali-

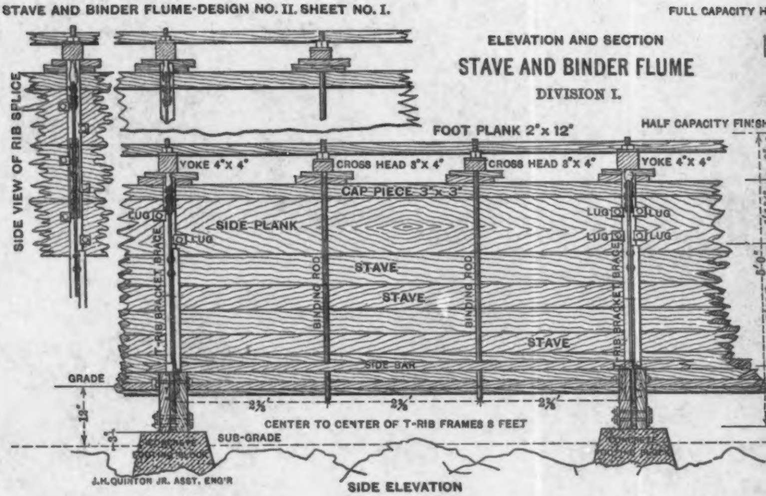
fornia shops, so as to prevent excuses for high bids, was the reason for this omission in the specifications. These rods pass through 3 x 4-in. Oregon pine cross-ties (laid flat), and the nuts screw down on wrought-iron washers large and thick enough to serve as bearing-plates on the wood.

The ribs are of 2¼ x 2¼-in. T iron, weighing 4 lbs. to the linear foot, and machine-bent to the form desired, with the flat flange inwards and the rib of the T outwards of the frame. Thus, the staves have a 2¼-in. flat rest against the ribs. A flat key-eye strap of iron, bolted to the flange of the rib at each end, extends vertically up through the wooden cross-head, and through this eye a steel wedge-shaped key is driven in the plane of the frame (in direction across the flume), and acts as a wedge on the inclined surface of a wedge-shaped bearing plate, which rests on top of the cross-head. This constitutes the means of compression provided on the T ribs, under the ironwork specifications, but for comparison a number of the ribs were afterwards fitted in the company shops with screw-bolt heads, to be operated substantially the same as those of the binding rods. This latter arrangement proved the best, and would have been the cheapest. Here, again, with less haste and time for the manufacture and setting up of a small sample piece of the work before it was all specified, a betterment and an economy would have been effected at one stroke.

For the ribs having straps and wedge keys, the cross-heads are made of two pieces of 2 x 4-in. Oregon pine, held together upon thick cast-iron separators by five screw bolts. Before being put together the two parts of the yokes were cut to admit of the passage of the straps between them, and the greater expense of mortising was thus saved. The plates over them are broad and thick enough to do away with the disadvantage of separating their bearings into two parts. The yokes for the ribs which have screw-bolt heads are of 3 x 4-in. Oregon pine, the same as those used with the round binding rods.

The bolster, or sill, is made of two pieces of 2 x 12-in. Oregon pine (about a tenth of the number were made of redwood), firmly held side by side and ½ in. apart by five screw bolts, each of which has a ½ in. thick cast-iron separator strung on it between the two planks. This bolster sets edgeways upright on its bearings. Into a curved seat, cut in its top edge to a maximum depth of 5 ins., the rib rests for 4 ft. of its

STAVE AND BINDER FLUME-DESIGN NO. II. SHEET NO. I.



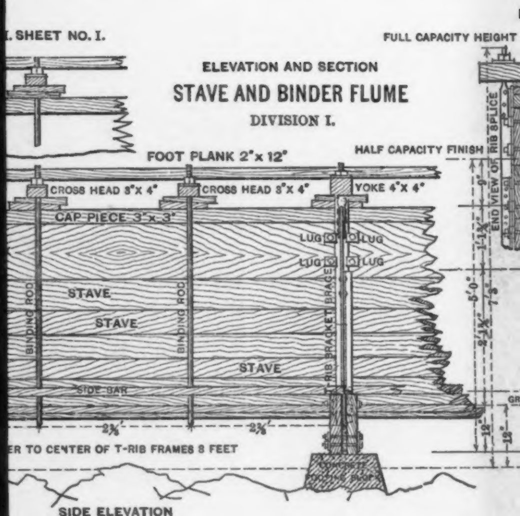

I. SHEET NO. I.
FULL CAPACITY HEIGHT
ELEVATION AND SECTION
STAVE AND BINDER FLUME
DIVISION I.
FOOT PLANK 2"x 12"
HALF CAPACITY FINISH
CROSS HEAD 3"X 4"
CROSS HEAD 3"X 4"
YOKE 4"X 4"
CAP PIECE 3"x 3"
LUG
LUG
LUG
LUG
STAVE
STAVE
STAVE
BINDING ROD
BINDING ROD
T-RIB BRACKET BRACE
END VIEW OF RIB SPLICE
SIDE BAR
2⅔'
2⅔'
ER TO CENTER OF T-RIB FRAMES 8 FEET
SIDE ELEVATION

PLATE XIII.
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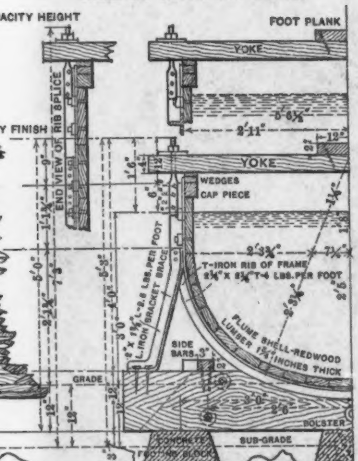


CROSS-SECTION WITH T-RIB IN VIEW

length, and with the rib of the iron T sandwiched between the two planks of the bolster.

On each end of the rib is riveted a brace of $1\frac{3}{8}$ x 2-in. L-iron, weighing 2.6 lbs. per linear foot. These bracket braces slope somewhat outward from the vertical below their junction with the rib, to give a broader seat to the iron-work as a whole, and, having their lower ends turned to afford a horizontal footing, are each firmly fastened to the top edge of one part of the bolster by two $\frac{7}{16}$ x 5-in. lag screws. The bolsters, braced ribs and their yokes thus combined are referred to as the frames. In making the bolsters it will be noticed that, whereas it is necessary for the bearing of the bracket braces to carry one part out to a square ending, the other part may be cut diagonally, thus saving 1 ft. length of lumber in cutting to each bolster.

In the Santa Ana Canal flumes the side planks are held out to the ribs by two lug pieces to each plank and rib, each of which is fastened firmly to the plank by a large threaded lag screw, intended not to go through the plank. There being but one lag screw to the lug piece, the latter in casting were provided with two little points which, in screwing them against the planks, are pressed into the wood, thereby preventing turning and consequent cramping against the edge of the rib.

As already stated, the object of the location was to put the flume as much as possible, at reasonable expense, on a full-width bench, where it would not depend on posts or other timber underpinning for support. Accordingly, by far the greater number of the sills rest directly on concrete footings which were made in place on the solid rock of the bench. Where the foundation is of earth or other than rock not likely to crumble, the footings are of redwood blocks on mud sills of the same lumber. Where supported by trestles or girder spans, the sills of the flume rest directly on the stringers. Where supported on posts, without the intervention of a stringer or girder—as was admitted where not more than one sill in a place and for not more than one of its three bearings was in the air—a cast-iron piece acting as a cap for the post and which cannot slip off it, and as a rest for the sill off which it cannot slip, is used.

The iron-work of this flume was furnished all together, by contract, at one price, under specifications and according to plans on which bids were invited. The contractors were the Baker Iron Works, of Los Angeles, Cal., who devised a machine for bending the T-ribs to the

oval form desired, and who turned out very good and uniform work. The T-ribs and binding rods were treated to two coats of red lead, the cast-iron work was immersed in a hot asphalt bath and other parts in hot oil.

As shown by the larger scale section, the flume shell is composed of one center plank $9\frac{3}{4}$ ins. wide on outside, 16 staves, each $5\frac{3}{4}$ ins. outside width, and two side planks, $11\frac{3}{4}$ ins. wide each, on top of which on each side a harder wood cap or edge piece, 2 x 3 or 3 x 3 ins., was afterwards placed as hereafter explained. Being dressed out from lumber of standard dimensions, the actual widths specified and drawn for patterns for planks and staves had to be in each case $\frac{1}{4}$ in. narrow. In like manner, having been dressed down from 2-in. lumber, the planks and staves are but little more than $1\frac{3}{4}$ ins. thick. There being two different curves to fit in the oval, there were two different patterns for the cross-section forms of the staves. Two staves on each side of the center plank are edged to the radii of the larger curve and the balance to those of the smaller curve, notwithstanding the seam between the two forms misses the point of juncture of the two curves by nearly half a stave width.

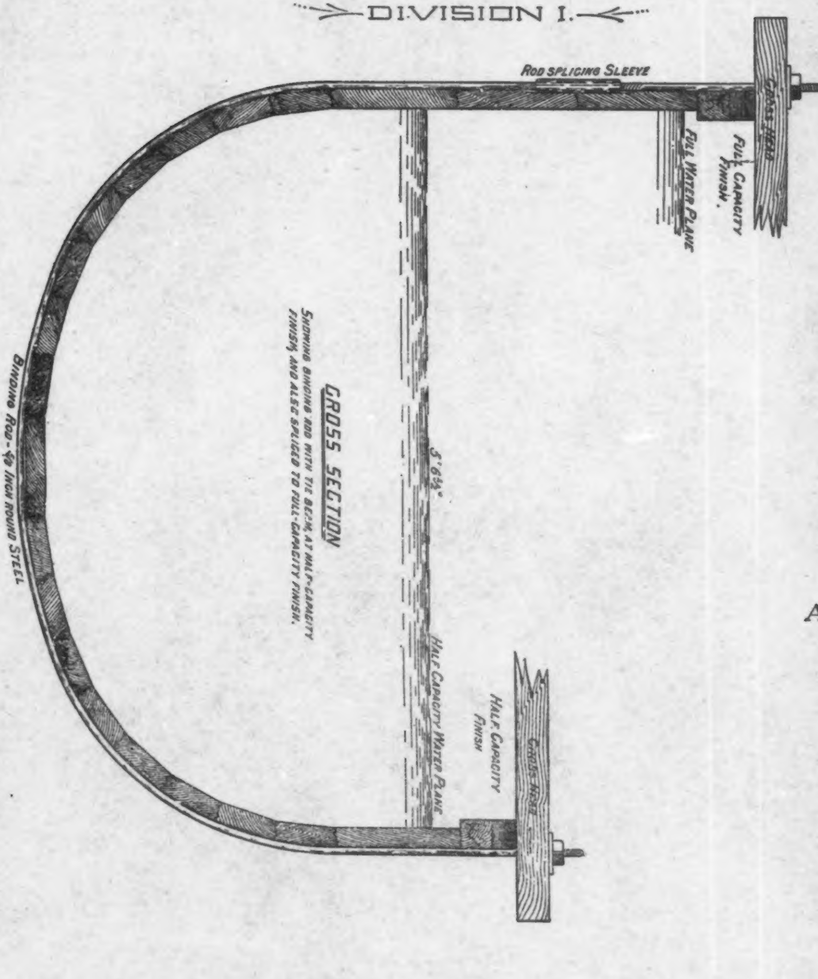
This lumber was obtained by contract under specifications, and dressed to the forms furnished. It was to have been not only selected, but well seasoned and dried before working. But, as matter of fact, while the quality was good, most of it was quite full of sap or water when delivered. The lumber company had to fill the contract at the season of year when rain prevailed almost every day in the region of their mills, and had been falling throughout the winter. The order being a very large one for one thickness of high-grade stuff, strict compliance with specifications on this point probably could not reasonably be expected. At any rate, the Irrigation Company had to accept very wet lumber for the staves or not get the work done. Nevertheless, these had from two to four months in the very dry climate of Southern California in which to season before they were finally bound in the flume, and yet it was no uncommon circumstance to compress the shell in the process of final cinching, as much as 1 in. on each side, after it had shrunk and been drawn down 1 to 2 ins. on each side in the seasoning.

As will be seen on the larger scale section (Plates XIII and XIV), the staves and boards composing the shell each have an $\frac{1}{8}$-in. bead run in its edge one-third the thickness from one side. The compression, of

PLAN AND SECTION

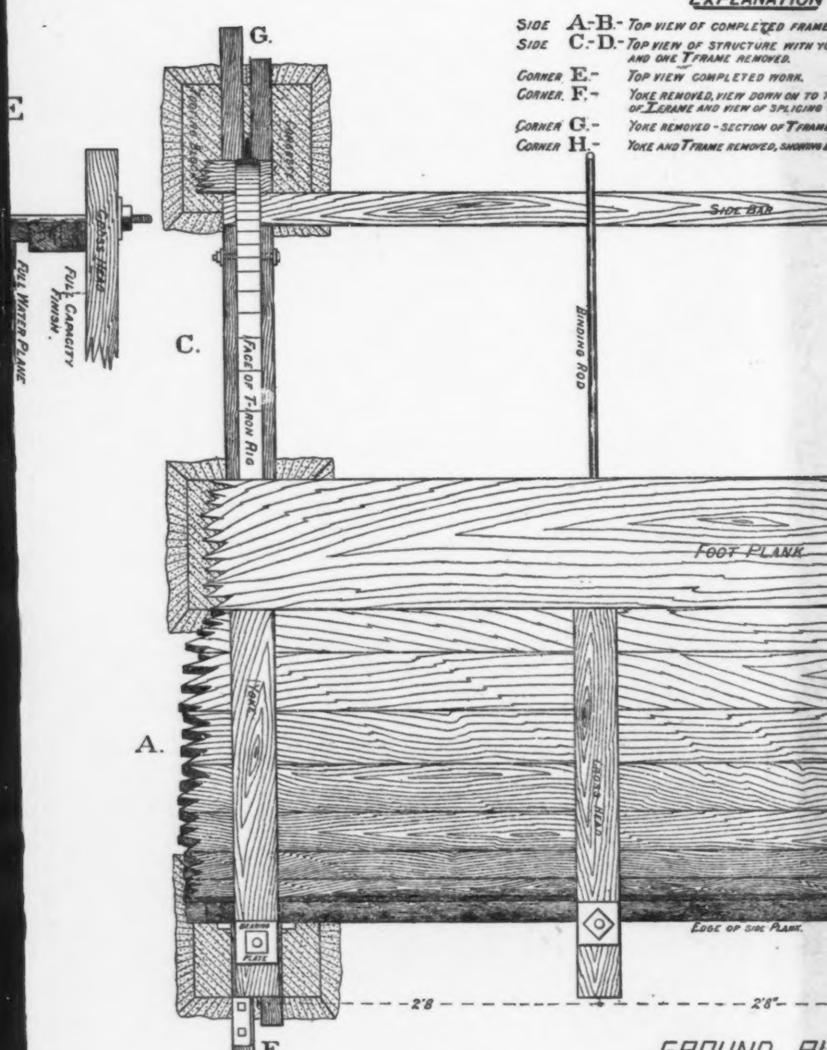
STAVE AND BINDER FLUME

DIVISION I.



EXPLANATION

SIDE A.-B.- TOP VIEW OF COMPLETED FRAME
SIDE C.-D.- TOP VIEW OF STRUCTURE WITH YO
AND ONE T FRAME REMOVED.
CORNER E.- TOP VIEW COMPLETED WORK.
CORNER F.- YOKE REMOVED, VIEW DOWN ON TO T
OF T FRAME AND VIEW OF SPLICING
CORNER G.- YOKE REMOVED - SECTION OF T FRAME
CORNER H.- YOKE AND T FRAME REMOVED, SHOWING



GROUND PL

SHOWS UPPER EDGE OF FLUME SHELL WITH R

PLATE XIV.
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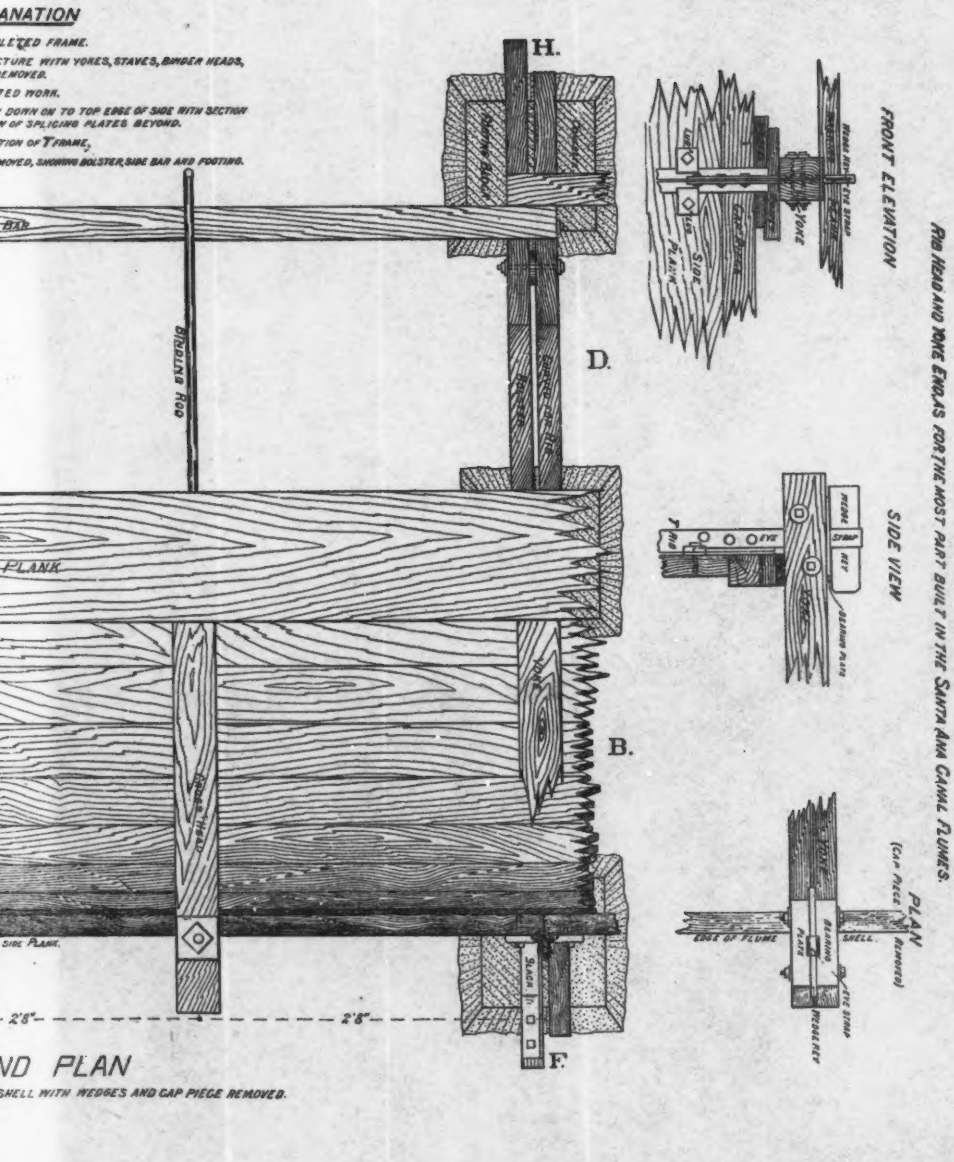

course, sunk these beads each into the edge of the abutting stave, thus forming in each longitudinal seam two little tongues and grooves, as it were.

The flume shell was for the most part built in lengths or sections, from rib to rib. Where the alignment is straight, the lengths are 16 ft., covering two bents; and where in curve they are only 8 ft. long, from frame to frame. In tangent, of course, the ends of all planks and staves are square cut, and the butt joints come squarely in the middle of the T-ribs. Where in curve the plank and staves had to be sawed to fit, and it was found that the simple way of fitting and scribing each plank—the carpenters working in pairs, one at each end of the plank—was the most expeditious. These workmen became very expert at what was really a difficult piece of mitre carpentry, and the staves as cut in made very close end joinings. But several weeks of summer sun on the lumber thus lightly cinched in the frames shrunk the redwood lengthways, so as to open the end joints $\frac{1}{8}$ to $\frac{3}{16}$ in., thus to a great extent doing away with the use of the spreading iron preparatory to calking. This calking was done with oakum, on top of which, to a third of the total depth, the seams were payed with hot asphalt.

On some of the longest tangents, as, for instance, on that across the steel bridge, the flume shell is laid with broken joints—only three or four butt joints (of the 19 staves, including bottom and side planks, each 16 ft. long) being made against any one rib; and the balance of these joints being distributed, according to a system, between the ribs. The butt joints of this construction are closed on metal tongues let into saw cuts in the ends of the staves and planks, as is done in wooden stave pipes.

The sills and yokes were milled, put together and dipped in hot coal tar, in the company's yards, and the steel binding rods were there bent to form, also. These and all other parts of the construction were hauled to and distributed along the work in due proportion and quantity, in accordance with schedules prepared for each point of delivery and route of subdelivery. The concrete footings had been put in some weeks in advance, to admit of hardening, when flume construction commenced.

After subdelivery along the bench, of all the materials except the staves and side boards, a gang of four men in advance put the yokes on

the ribs, and the ribs on the bolsters, and otherwise prepared the frames and assembled the small materials in place for each bent. One of these men was a carpenter; the others, laborers.

Two carpenters and two laborers, under a foreman carpenter, followed, setting up, centering, spacing, and orienting the frames to the radii of the curves, and fastening them up in place by nailing the side bars to the sills, temporarily nailing a light furring stringer on each side to the ends of the yokes, and cutting and nailing on the walking plank.

The staves and side boards were then subdelivered along the footway, and assorted and piled in due number, continuously, on top of the yokes. Carpenters, working in pairs, then cut and fitted these into the shell, and lightly set the wedges in the T frames to hold them. Following came a cinching gang of five men under a foreman, who put on the lug pieces and the binding rods and their cross-heads, put in the balance of the wooden wedges, and lightly cinched and wedged the yokes and cross-heads to their bearings. As this was done, the staves were hammered out with a heavy covered mallet to a smooth jointing on the inside and firm bearing against the ribs. This tightening and matting out was repeated at least twice during the month succeeding, as the lumber dried and shrunk; then a tight cinching was given, and, finally, the butt end joints were calked and payed by a special gang, and the water was turned in soon thereafter.

Although this experience has shown that for a flume of this size the screw-bolt head for the ribs is to be preferred to the strap and wedge-key over the yoke, it has also shown the necessity for the wedges between the yokes and cross-heads and the top of the side plank. Without these wedges the screw threading would have to be very much longer, and much more labor and time would be consumed in getting a hold and a bearing. These side wedges have to be freely used at first to take the edgeways warp and spring out of the planks and staves. When the lumber has been well seasoned in the work, and before the final cinching is given, a 2 x 3 or 3 x 3-in. hard-pine continuous edging or cap piece (laid flat, if 2 x 3) may be substituted for all but one pair of the wedges to each bearing, thus giving a good top finish to the shell and a broad bearing for the yokes. This was done on a portion of the Santa Ana Canal flumes.

The edgeways spring of the staves, no matter how well and care-

PLATE XV.
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fully seasoned the lumber, frequently causes, in the aggregate, as much as 4 ins. of space on each side, between staves, which has to be closed down when a shell of this kind is first put together. This causes difficulty in getting the cross-heads over the binding rods if there is not extra rod-length to spare. If side wedges are used this extra rod-length need not be provided, and the rods need not be upset and threaded more than 3 ins. in length. For, after the cross-head is on, the side wedges are inserted and quickly take up the space, as the warp and spring is taken out of the staves; and this leaves the screw and nut movement available for the real cinching which follows in at least three repeated operations, as already described. The use of temporary cinching bands or straps in course of construction, to clamp the shell while the permanent rods are put on and caught to the cross-heads, was found to complicate the work and increase the labor cost, and is to be resorted to only in cases of bents holding excessively sprung staves or side boards.

It will be observed that the side bars and the foot plank act as continuous stringers, and experience has shown that they serve to prevent any disturbance of the structure beyond the part hit, when, by a landslide or falling rock, a bent or length or two of the work is carried away. On wider flumes of this kind, it would be well to put side bars or stringers permanently along the top of the structure—fastening them to the yokes, or directly to the ribs—in addition to those which are spiked to the bolsters below. And on deeper works it might be well to introduce some longitudinal bracing on the outside of the shell and between successive bents and frames. The great amount of curvature, however, has served to diminish the necessity for bracing of this kind on the flumes of the Santa Ana Canal.

To prevent the waters washing over the outside edge on curves, the flume is given transverse slopes of 2, 3, 4, 5, or 6 ins., according to the degree of curvature. In doing this the center bearings of the bolsters or sills are kept true to the running grade, the inner bearings on the curves are dropped half the desired transverse slope, and the outer bearings hold up the other half, the tops of all three being properly sloped. And then, in passing from curve to tangent and the reverse, the change is made gradual, by the eye, in setting the frames. The result gives a noticeably winding or twisted appearance to the finished structure, where the curves are sharp and reverse quickly.

This adjustment complicated the work much at every step, especially the setting of frames and cutting in the staves. When, however, it is remembered that the mean velocity of water, when flowing full in the completed work, will be about 9.6 ft. per second, and that for economy and compactness the cross-heads are to be only 8 ins. above the water's surface, the necessity for the arrangement will be apparent without the labor of calculation.

In this whole flume structure there is not a nail driven except to fasten the side bars to the sills, and the foot plank to the yokes, and, except temporarily to tack strips of furring in place as stringers, to hold the frames during construction. The parts and bearings where decay starts in ordinary wooden frame flumes are not found in this, and the structural faults of flumes of ordinary building which lead to decay it is thought are eliminated by this design.

The wooden-frame flume commences to rot where the ends of the side posts rest on the sills, and between the planks and the frame, and between the side boards and the bottom boards. Nail holes start decay. The planks of ordinary flumes are nailed to the frames. According to the stage of water, they alternately become dry or nearly so, and again are swelled. Joints open and leak, nails are loosened and leakage occurs around them. Dust lodges in the seams and corners, especially where wet from leakage, and decay follows. And then, when repairs become necessary, the structure has, virtually, to be torn to pieces and built over again, to accomplish a good result.

These special evils, it is hoped, are prevented or in very great measure diminished by the design of the Santa Ana Canal flume. There is no wooden frame to rot at its joints; no plank within a wooden frame to start rot where wood rests on wood; no nail holes to be opened by swell and shrinkage; no leak to start rot. For the Santa Ana Canal experience has proven that this class of flume can be made absolutely water-tight, and a reasonably intelligent and careful attendance (tightening the shell by the screw-nuts and wedges, as the water falls in the autumn, and loosening it, if necessary, as it rises again in spring) will maintain it practically in the same condition. Being kept tight and not accumulating dirt in their cracks and joints, the staves will resist decay for many years. Resting on iron and not on wood outside, their life at these bearings will be very materially increased. The sills, made open, so as to ventilate freely, and for the most part bearing on

concrete below and supporting contact with iron only above, and not being subjected to frequent wetting from a leaky shell, will have a long life. And the same, only in less degree, may be said of the yokes and cross-heads, for they have no nailed joinings with the tops of wooden side posts, or any part specially subjected to decaying influences.

When serious accident comes—and in locations such as the Santa Ana Canal flumes occupy, accidents surely will come from landslides and falling rocks—it is an easy and expeditious matter, as several experiences have shown, to clear away the wreck, with the kind of flume there constructed, and build in a new piece. When decay commences and a plank or stave needs to be replaced, a bent or length of the shell can be quickly taken out, the faulty member rejected, and a new piece put in its place. If it appears that the iron of the binders is rusting, they can be dropped off, half the number at a time, painted all round and put on again without stopping the water's flow. When it appears that the iron of the ribs is rusting next the shell, or the wood of the shell is decaying in that bearing, during the season when the flume is not in use the whole shell can be "knocked down," the ribs cleaned and painted, the lumber swept clean and tarred on the ends, and replaced, for a sum that will be small compared to the value of the new life given the structure.

As stated, the Santa Ana Canal flumes are finished to half the intended capacity only, and the expectation is, ultimately, to raise the ribs and put two more planks on each side. This operation is a simple one. The yokes and cross-heads are removed, the straps or bolt heads taken off from the ribs; the ribs spliced at each end with a straight piece of the same T-iron fastened on with a pair of fish plates bolted by the holes already in the iron; the bolt heads or straps placed on the top ends of the ribs thus lengthened; the same yokes replaced and the ribs enlarged, are ready. The binding rods are spliced by any one of several ways which will be apparent to the engineer; additional side boards put on and lugged out to the ribs; the cross-heads and yokes cinched down; the new butt joints calked and payed, and the work is accomplished.

Such enlargement can be carried on even while the flume is in use, by working one bent at a time in any one place, and it will be seen that it is attended with no sacrifice of the structure as built, and can

be accomplished with a proportionately small amount of labor and material.

Thus it is believed that, although this flume cost somewhat more than would an ordinary one of equal capacity, considering the points above brought out, it will have cost no more when enlargement is completed, and will be still a good flume when two ordinary flumes in succession would have rotted away.

Cost of Flumes.—Division I.—There are nine reaches of this flume, aggregating 11 394 ft. in length, and not including 34 ft. of laps into masonry and concrete structures, built in the cañon division of the work at a total cost of $51 392 50. This included all cost of grading the flume benches, through cuts, and cuttings in the tunnel approaches whereon the flume rests, all substructures and foundations, all delivery and subdelivery of materials—in fact, every cost chargeable, except roads and skidways for delivery and subdelivery purposes, tools and implements, superior superintendence, engineering and accounting.

With respect to parts of construction, this expenditure is subdivided as follows:

Grading—Tunnel approaches—Contract work....	$3 388 14	
Bench and cuts—Force work	15 110 96	
Total	———	$18 499 10
Flume foundation—Excavation	$345 51	
Concrete footings........................	769 64	
Redwood footings........................	192 30	
Total..............................	———	1 307 45
Substructures—Excavation of foundation.......	$166 75	
Masonry footings........................	520 40	
Trestles, girders, trusses, etc.............	2 572 73	
Delivery and subdelivery...........	389 00	
Total..............................	———	3 648 88
Flume—Materials..............................	$21 377 96	
Labor.................................	3 949 28	
Delivery and subdelivery.................	2 609 82	
Total..............................	———	27 937 06
Total over all.......................		$51 392 49

Averaged over its actual length, including tunnel approaches and excluding length of substructures, the bench grading cost $1 78 per linear foot; or, for the flumes' length, which would include length of substructures, the bench grading cost $1 62 per linear foot. Grading in tunnel approaches, under the tunnel's contract, cost $7 53 per linear foot. This last could have been done on force account, even under prevalent adverse labor conditions, for about $5 per linear foot. Force account grading, over all, cost $1 52 per linear foot; of which that in heavy cutting cost about $4, the ordinary location about $1 25, and the cheapest full bench about $1. Under normal conditions of labor and with efficient superintendence these costs would have been reduced, on the average, about 22 per cent. The concrete footings in this division cost about 9 cents per linear foot of flume supported by them, and the excavations to place them cost 4 cents, making a total of 13 cents for this class of foundation. The wooden footings cost 10.4 cents, in place, per linear foot of flume supported by them. Averaged over all, the cost of foundations was 12.6 cents. This, with the average of bench grading, brought the flume support, on bench, to an average cost of $1 74 per foot of line. The flume substructures averaged $3 56 per foot, or 32 cents per linear foot of flume in the division. The average cost of flume support—grade, foundations and substructures—was $2 06 per foot of the flume. The total cost per foot of flume was $4 51, of which $2 22 was for the flume alone, and $2 29 was for transporting its materials, preparing the grade, foundations and substructures for it and putting it in place.

In division II there are six reaches of flume, 1 491 ft. in total length, resting on the wooden trestles and combination trusses elsewhere described (see Fig. 2, Plate XI), and one reach of 1 215 ft., held by the steel bridge and approaches thereto. The cost of this latter piece is given in connection with that of the bridge. The flumes of this division, as now finished for use, are 6 ins. deeper than those in division II—the sides are that much higher—and, consequently, the cost of the iron and lumber in the conduit proper was greater per linear foot of the structure. The labor item in the following account of cost also includes extra work, of no inconsiderable importance, on the six tapering entrance pieces from canal to flume. As these flumes rest on the substructures, except for about one 8-ft. length each, there is no charge for grading or foundations for them.

Subdivided as in the case of flumes in the first division, the cost of these in division II was as follows:

Substructures—Foundation excavation..........	$217 50	
Masonry footings and piers...............	720 55	
Trestles, girders and trusses..............	2 279 73	
Delivery and subdelivery.................	298 00	
Total...............................	———	$3 515 78
Flumes—Materials..........................	$2 688 12	
Delivery and subdelivery.................	165 50	
Labor....................................	771 89	
Total...............................	———	3 625 51
Total over all........................		$7 141 29

The substructures in this division, with a total length of 1 440 ft. measured along the stringers, cost $2 44 per linear foot, or $2 35 per linear foot of flume. This latter cost $2 43, making the total cost of these portions of the aqueduct $4 78 per linear foot, and the flume on substructure $4 87 per foot.

Pressure Pipes.

The three pressure pipes of the line cross Warm Springs, Deep and Morton Cañons, respectively. The first named is not a sharp cañon in section; the two latter are exceptionally so. The pipes are of redwood staves bound with round steel rods, and with the end joints closed by metal tongues let into saw kerfs in the stave butts. This latter feature and the special form of coupling used for the binders are the protected elements in what is known as the Allen patent stave pipe. The Excelsior Wooden Pipe Company, which controls this patent for California, were the contractors on the work. And D. C. Henny, M. Am. Soc. C. E., as engineer and manager of this company, planned the structural details of the pipes and directed their building under the specifications. The foundations, supports and bearings for the pipes were put in by the Irrigation Company by day labor, independent of the Pipe Company's contract.

The controlling reason for adopting wooden, and not iron or steel, pipes for these crossings, was that of saving in cost. It must be remembered, not only that the suitable wood for such pipes is cheap on

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the Pacific Coast as compared to eastern localities, but also that iron and steel, as well as the class of labor necessary to manufacture and put great metal pipes in place, are all, by comparison, high priced on this coast.

And, again, wooden pipes could, with several points of vantage, be laid wholly above ground, thus saving cost of excavation and back filling, which, at the localities dealt with, would have been excessively high; while, on the other hand, it was thought that, owing to the great range of temperature to which they would be subjected, and for other reasons, metal pipes of such very large size would have to be either placed wholly in earth or be expensively anchored and housed.

In this connection, the alternative of doubling the number and diminishing the size of the pipes was preliminarily planned and estimated upon. But when the loss of velocity or necessary increase of hydraulic grade to maintain it, and necessary accumulation of head to force entry, increased width of foundations and of substructures, increased cost and complication of end junctions, and the greater cost of the pipes themselves, were considered, the idea was abandoned. Though it may at first seem a simple proposition to divide the waters of a large flume, having a full-flow mean velocity of 9 to 10 ft. per second between four pipes, and bring them together again into a flume, and maintain good hydraulic conditions uniformly throughout, in fact it is a difficult problem, and one whose reasonably successful solving makes much more expensive work in the junction structures than will ordinarily be justified in irrigation engineering.

As intimated, the reason for putting the wooden pipes above ground rather than in earth is not wholly found in the point of economy, for it is believed that their materials will be less subject to decay when freely exposed to the air; and thus placed, they can be conveniently inspected and kept in repair. Experience in Southern California has shown that sound wood, not subjected to alternate water soaking and drying out, and far enough from the ground surface in the open air for good ventilation and freedom from soil influence, has a very long life. On the other hand, it has here been most abundantly shown that all woods rot rapidly at the ground surface and in the ground, and where subjected to wetting and drying; and, moreover, that there are some soil ingredients which have special wood-decaying influences, and others that attack and rapidly destroy iron and steel.

Owing to irregularity in the ground profiles of all the cañon crossings, it would have been impossible to put the wooden pipes under ground, even for only three-fourths of their length, without either introducing metal elbows or incurring an expense for cutting through high points, absolutely forbidding in amount. Such large pipes cannot be built on curves of materially less radius than 250 ft. with staves 2 ins. thick, or less than 300 ft. with staves 2.6 ins. thick. For be it understood that curvature in these pipes is attained by forcing a bend, by means of jackscrews, blocks and tackles, or other power appliances, after the staves are put into pipe form and loosely banded and as construction proceeds.

As the above were the stave dimensions thought necessary to be used in the Santa Ana Canal pressure pipes, and as the ground lines undulated on curves of much smaller radii than 250 ft., the pipes could not be built to follow the surface profiles. Metal elbows were deemed objectionable, not only as diminishing the pipe capacities, but as increasing the cost, and as very materially increasing the liability to decay, leakage and failure at the points of joining with the wooden pipe.

By the best adjustment of grades that could have been effected, with the curves allowable, and by limiting the maximum depth of excavation to twice the pipe diameter below the present grade line, which itself even necessitated heavy earth and rockwork, not more than half of the aggregate pipe lengths could have been entirely covered, and about half of the balance would have been only partly covered; and besides this great proportion of the pipes thus subjected to the worst influences for decay, there would have been 14 points of the pipes' entry into and exit from the earth, all again specially presenting rot-producing conditions. And even thus the pipes would have been wholly in air, over the waterways, in the cañon bottoms, and for one-fourth their aggregate length. To go under these cañon waterways would have necessitated four sharp elbows to each pipe, and a heavy expense for excavation, back filling and paving. It is true that the expense of the trestle supports was the alternative; but this was figured at less than the extra cost of burying the pipes.

Moreover, the cañon sides on the two principal crossings were so steep that the back filling would not have consolidated in place; and this, for several reasons apparent enough to the profession, would

have left a bad condition of things. The rocks and soils very perceptibly contained some alkaline or other mineral matters which might attack the wood actively, or the steel of the bands, or both. And, altogether, had the attempt been made to place these pipes under ground, the conditions were such as would conduce to their rapid decay. It will be understood, of course, that there will never be any danger of ice forming in these pipes, and that no reason exists on this score for burying them.

The Bear Valley Irrigation Company has a 48-in. wooden stave pipe, having 3-in. thick staves and under a pressure too light to keep them well saturated, exposed for its full length, of more than a quarter of a mile, in the open air. It is now six years old, and the wood is as sound to-day, inside and outside, as the day it was put in. There is no appearance of deterioration at any point, either of the wood or the steel bands.

Again, the Santa Ana Canal pressure pipes are not coated with coal tar, asphalt or any other supposed preservative substance, because, under the circumstances, it is believed to be the best practice not to coat them. The long life of wood in such pipes is due to its being continuously saturated with water; and, this being the case, the freer scope for action given the water, the better. Not coated, these pipe staves will be saturated through, practically to the outside, to where the water will slowly evaporate, and it is thought that this constant supply of fresh water to the pores will constitute a condition most favorable to the long life of the wood. Under such conditions neither coal tar, asphalt, nor any other coating would do any good; for the wood, being constantly wet, will not be harmed by the air, and, unless the wood is dry when application is made, neither asphalt nor coal tar can be made to go into the pores so as to keep the air out or form an efficient coating.

The lumber of these pipe staves was exceptionally fine in quality, but it was not dry; much of it was quite wet, and after placing in the work it could not, without great detriment, be allowed to dry enough to take a coal-tar or asphalt coating. Moreover, at the season of the year when required under the contract, it probably could not have been furnished dry enough for coating. But suppose the lumber had been seasoned sufficient for coating, such coatings have to be renewed about every four or five years in Southern California, to keep

their influence alive. Now, these pipes can never be allowed to dry sufficiently for a repetition of the coating process, and the writer maintains that a poor or greatly deteriorated coating is worse than none at all on the lumber of a wooden pipe.

The above relates to coating such pipes after construction, and on the outside only. The idea of dipping wooden staves into a bath of asphalt or coal tar before building into a pipe to be under pressure, the writer did not entertain in connection with the work herein described. Experience with woods on the Pacific Coast, redwood especially, pronounces against such process for this purpose.

If it were a seasoned timber stick or plank to go into a dry structure, and especially if near the ground, like the sills of a flume or pipe bearing on a foundation, complete coating with coal tar or asphalt has its beneficial effect in Southern California. Or, if the pipe were to be placed in earth, the exterior coating, especially of asphalt, keeps the soil from it and helps to prolong its life. But for a wooden pipe continuously under water pressure from within, and placed in the air, the natural wood surface is believed by the writer to be the best, and the Santa Ana Canal pipes are evidence of that belief.

The writer is thus specific in stating this case because professional opinion, from high authority, has been privately advanced (though, it is believed, thoughtlessly) to the effect that it would, by insuring a longer life for the pipes, have been better to put them under ground; or, being above ground, they should have been coated. Moreover, this is a subject yet new to the profession and may with profit be discussed.

To one who has not previously considered these points, and especially not in connection with locations similar to those of the Santa Ana Canal pressure pipes, somewhat of a shock may come on seeing them thus exposed to the intense heat and apparent desiccating influence of a Southern California sun and atmosphere.

But for reasons which have now been stated, as well as others which may, at least, be apparent therefrom, the writer is strongly of the opinion that in Southern California wooden stave pipes which are to remain continuously filled with water under pressure sufficient to keep the wood well saturated will have longer life in the air than in the ground, and cannot be benefited by coating; and, that, especially, it would have been a mistake to attempt to put the Warm

Creek, Deep and Morton Cañon pipes of the Santa Ana Canal under ground.

The Pipe Problem.

The pipes herein described are not anchored or held in place, except as they rest in their bolsters and except at their ends where built for water connection, into the masonry of the junction bays. Notwithstanding the steepness of the cañon sides on which two of these pipes rest, and notwithstanding the horizontal and vertical curves in them, the writer does not think it necessary to anchor them, and conceives that at first it might have led to trouble.

Let it be remembered that these pipes are immensely stiff shells of large diameter. As columns to resist springing out of line from longitudinal compression strains, and as tubes to resist buckling inwards from similar strains, their strength is much greater than necessary to meet any stress which will be brought to bear on them, except it be occasioned by a landslide ; and any reasonably cheap anchorage would not avail against such a mishap.

They are open butt conduits, through which not more than a moderate (the normal) velocity can be induced, and to which no shock of "water-hammer" can be imparted. Because wrought-iron pipes, equally strong to perform the primary hydraulic duty required at these crossings, would have to be anchored, if not thoroughly buried, to prevent danger of springing out of line and buckling, can be no reason why the expense of anchorage should be added to the cost of the Santa Ana Canal wooden pressure pipes. Such wrought-iron pipes would not have the qualities to preserve their alignment and form which these wooden pipes unquestionably have.

Carrying out the idea of first finishing the work for half-duty throughout its length, these pressure-pipe crossings are planned for two pipes each. The grading, foundation and trestles, and the connection structures at each end, are made ready for the two pipes in each case, but only one has been built for each crossing. This is 52 ins. in diameter, and is expected to carry 120 cu. ft. per second.

The specifications called for staves 2 ins. thick throughout in the Warm Springs pipe. For all pressure heads under 50 ft. in the other two pipes the thickness was to be 2 ins.; from 50 to 100 ft. of head the staves were to be 2.3 ins. thick, and for all heads over 100 ft. the thickness was to be 2.6 ins. Dressed from 6-in. standard width material,

the staves are about 5¾ ins. wide. A ¼-in. bead is run on one edge of each stave, and the sides are rounded to the curves of the pipe's circumference. The lumber was all beautifully clear and sound, but not as well seasoned as was expected and desirable.

The lowest part of the Deep Creek pressure pipe, where it is in vertical curve of 300 ft. radius (to center of pipe), for 32 ft. in length is supported on a pair of trussed girders.

The writer believed that there was no necessity for giving the trusses additional strength to meet any supposed load due to either a downward thrust or bulging tendency, which theoretically would be consequent upon the greater hydrostatic pressure on the lower than on the upper half of the pipe in this upward vertical curve. The result has proved the correctness of this judgment.

Although the pipe has now been carrying its water for a year, the end plates of the truss rods in the span spoken of have never even been brought to their full bearings, notwithstanding there is a smaller factor of safety in their proportioning than in any other member of the truss. Not only do these plates not show any sign of crushing into the wood, as unquestionably would appear if they were so loaded, but they have never been brought to a snug bearing over all their surface on it. There is no evidence or indication, in any part or bearing, of the trussed girders being fully loaded, even, much less overloaded, or of the pipe pulling apart either side of them.

As a matter of fact, the appearances are such as to lead to a thought that this pipe is acting in a manner not understood, or, at least, not mathematically demonstrable, to relieve the trussed support of a portion of the load which as its designers the engineers of the Irrigation Company expected it would be subjected to.

In closing this point: As an experiment, with the pipe thoroughly well cinched, the writer would not hesitate to lay it as a tubular girder in 16-ft. spans, between bearings, to support itself and its load of water; and he does not believe that disaster would follow to the Deep Cañon pipe, even were the hog chain rods of the trusses in question loosened up so as to take no weight whatever, leaving only the string girder and the pipe to do the duty.

The Pipes.

Warm Spring Pipe.—The Warm Spring's pressure pipe is 551 ft. long and occupies 540 ft. in length of the line. The maximum head of

pressure from the full-water hydraulic grade line to the inside bottom plane at the lowest point is about 61 ft. The staves are 2 ins. (full) thick throughout. Where set closest together the bands are 5.5 ins. apart from centers, and 12 ins. is the widest spacing. Starting in a downward curve of 250 ft. radius, at a point 20 ft. from the curve's point of tangent with the flume grade plane, it follows on that curvature for 90 ft. in length; then after about 17 ft. of tangent on slope it curves upwards, with the same radius, for about 148 ft.; then almost immediately curves horizontally to the right again with the same radius, while laying on a sharp up grade for about 265 ft. of length, and finally bends down with the same degree of curvature for 41.5 ft., and so enters the lower junction bay. It is on trestle and trussed girder supports for part of its first downward and all of its upward curve, and altogether for 211 ft. of length. The balance of its sills rest on concrete footings.

Cost.—With its substructures, foundations and grading, the Warm Spring's pressure pipe cost $3 513 95, distributed as follows:

Grading		$262 65
Foundations—Excavation	$10 50	
Concrete footings	51 00	
Total	——	61 50
Substructures—Excavation of foundations	$42 75	
Masonry piers and footings	242 72	
Trestles, girders, trusses, etc	646 38	
Total	——	931 85
Sundries—V flume	$53 25	
Miscellaneous expense	10 00	
Total	——	63 25
Pipe—Contract work		2 194 70
Grand total		$3 513 95

This is at the rate of $6 51 per foot for the whole, or $4 06 for the pipe alone, $2 33 for the substructures, pipe foundations and grading averaged over the length of the structure, and 12 cents for sundries. For the length of pipe supported by them, the concrete foundations cost 19 cents per linear foot, or, with the pipe, $4 25. For its length the substructure costs $4 21 per running foot, or $8 27 with the pipe on it complete.

Deep Cañon Pipe.—The Deep Cañon pipe is 964.4 ft. long, and occupies 908.2 ft. in length of the line. For about 405 ft. of length, where, under the greatest pressure, its staves are 2.6 ins. thick, then, each way, for 253 ft. total, they are 2.3 ins., and the 307 ft. remaining have 2-in. staves. The maximum head of pressure is about 160 ft., the closest banding $2\frac{1}{8}$ ins. from center to center of bands, and the widest 12 ins.

Leaving junction bay No. 3, it is laid with a vertical curve, downward, of 250 ft. radius, for 81 ft. of length; then on down slope of about 1 on 3.5, for 185 ft., of which 158 ft. is in horizontal curve, 250 ft. radius, to the right; then a downward curve of 300 ft. radius for 96 ft. in length; then, after 6 ft. of tangent, an upward curve of same radius for 316 ft., and then on an up slope of about 1 on 2, for 280.4 ft., into junction bay No. 4. Where in horizontal curve and on down grade, as above described, it is carried on a trestle 10 to 30 ft. in height. In the short tangent following the second downward curve it lies on a slope of about 3 on 4. For 249 ft. of its bottom curve it is carried on a trestle 30 to 50 ft. in height. There are three substructures aggregating 448.5 ft. in length, horizontally, under this pipe. The balance rests on the ordinary concrete footings.

Cost.—The cost of Deep Cañon pressure pipe, together with the grading, foundations and substructures, is shown by the following statement:

Grading		$1 256 10
Foundations—Excavation of foundations	$36 40	
Concrete footings	177 60	
Total	———	214 00
Substructures—Excavation of foundations	$175 50	
Masonry piers and footings	819 50	
Trestles, girders, trusses, etc	1 946 05	
Total	———	2 941 05
Sundries—V flume	$83 50	
Protection bulkhead	72 00	
Miscellaneous expense	30 00	
Total	———	185 50
Pipe—Contract work		5 631 10
Grand total		$10 227 75

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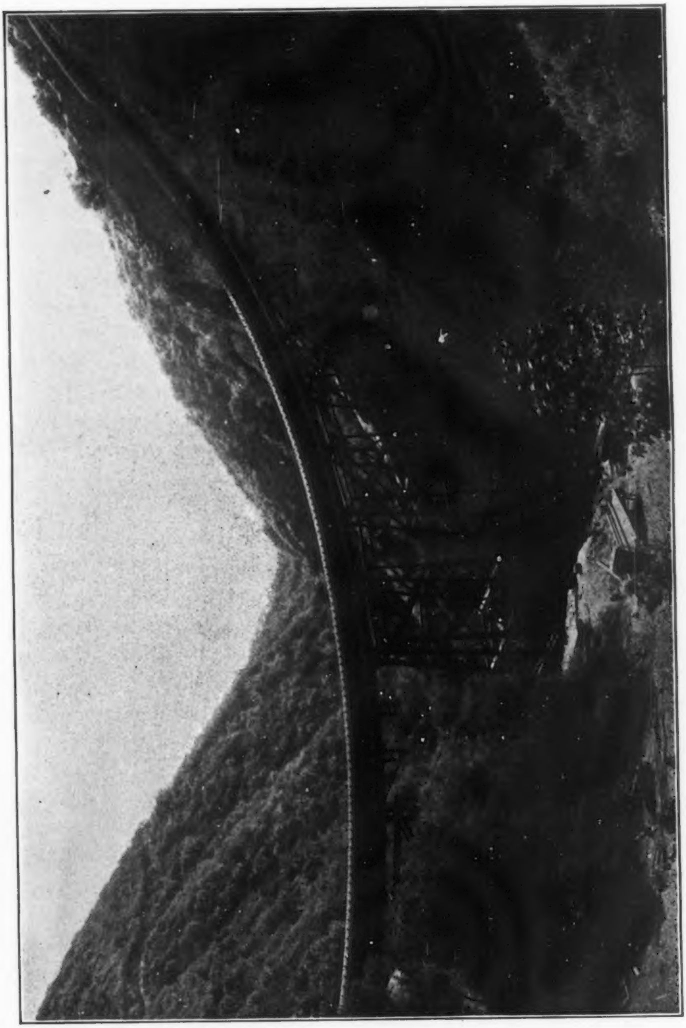

For its 908.2 ft. of length in the line of conduit, this total cost of structure brought the rate to $11 29 per foot, of which $6 20 was for the pipe alone; $4 85 for the grading, foundations and substructures, cost averaged over the length of the pipe, and the balance for sundries. The pipe foundations, exclusive of grading, cost 46 cents per linear foot of pipe resting on them, or, with the pipe, $6 66 per foot. The substructures cost $6 56 per running foot, or $12 76 with the pipe on them. These figures are all based on horizontal measurements.

Morton Cañon Pipe.—The Morton Cañon pressure pipe is 756 ft. in length, of which 717 ft. was constructed of the character already stated, under contract, and 39 ft. was built by the Irrigation Company. The entire pipe occupies 679.1 ft. of the running line. For 398 ft. of pipe length, where pressure is greatest, the staves are 2.6 ins. thick; then for 184 ft. total the stave thickness is 2.3 ins., and the balance, 135 ft. of the contract pipe, has 2-in. staves, as also all of that put in on force account. The maximum head of pressure is 158 ft.; the closest banding is 2⅛ ins. from center to center, and the widest is 12 ins.

Starting in a downward curve of 400 ft. radius, for 70 ft. of length, it then slopes down on tangent for 171 ft. of pipe—falling about 82 ft.—then curves up on a 310-ft. radius for 340 ft. in length, then rises 75 ft. in 136 ft. of length, where the contract pipe ends, and then curves over towards the horizontal with radius 70 ft. for 39 ft. of length into the lower junction bay. Where in upward curve, crossing the bottom of the cañon, it is carried on a trestle for 211 ft. of length and a maximum height of about 25 ft. The balance of the pipe rests on concrete footings.

The 39 ft. of pipe, in curve of 70 ft. radius, could not be built by the ordinary method of springing to the line desired in course of construction, so it was put in by the Irrigation Company's engineers in 8-ft. lengths, with an angle at each end joint. The staves were stagger-lapped 4 ins. at these joints, and joined with the flat-iron tongues, and the succeeding lengths were held together by special L-iron bands let ¼ in. into the staves and coupled with bolts. Otherwise the construction and banding were the same as for the balance of the pipes where under a similar head of pressure.

Cost.—The Morton Cañon pressure pipe, with its grade, foundation

and substructure, was somewhat complicated in cost by building the extension curve to join tunnel No. 9 in line in a different and much more expensive manner. The cost was as follows :

Grading		$586 60
Foundations—Excavation	$30 34	
Concrete footings	113 92	
Total	———	144 26
Substructures—Excavation, foundations	$68 00	
Masonry piers and footings	229 36	
Trestles, girders, trusses, etc	635 77	
Total	———	933 13
Sundries—V flume	$68 35	
Miscellaneous expense	20 00	
Total	———	88 35
Pipe—Contract work	$4 440 42	
Extension, force work	630 03	
Total	———	5 070 45
Grand total		$6 822 79

For the full length in the line, 679 ft., this structure cost at the rate of $10 05 per foot ; of which $7 46 was for the pipe (averaged over all), $2 45 for the grading, foundations and substructures, and 13 cents for sundries. The concrete foundations alone cost 31 cents per foot of pipe over them, or with the pipe, $7 77. The substructure at the rate of $4 40, or $12 06 per foot with the pipe on it. These figures, of course, relate to horizontal measurements.

Paved Canal.

The canal proper portion of the waterway thus far built is through heavy red clayey soil, carrying boulders, cobbles and gravel ; medium soils of the same general character overlying hardpan, and light, alluvial soils overlying boulders in sand and gravel. In all cases the canal excavation extends through the soil and into the underlying strata. It would be necessary, at least, to puddle thoroughly any waterway excavated through these materials, no matter what use the water was intended for or how much, within reason, might be spared for leakage ; for some portions would leak like a sieve without break-

ing, and others would be subject to frequent breaks without previously leaking. In Southern California, where irrigation waters command very high prices, and where waters of irrigation ditches are used for domestic purposes as well, there is to be attained the double object of economy and purity of supply by lining the canals.

Such canal lining is effected by the use of large cobbles and small boulders, laid with or without mortar, as pavements and sloping bank walls, or by the use of cement or asphalt concretes, or plasters variously proportioned and applied. As planned, almost all these varieties of canal lining were contemplated along the line of the Santa Ana Canal, according to adaptability of the materials cut through and convenience of lining materials for use. The constructed part of the canal throughout division II has been lined with large cobbles and small water-worn boulders, the side walls laid in mortar and all grouted and faced with a cement plaster. It is intended that none of the water shall be lost, and that it shall be kept pure for domestic use.

Two general ideas of shaping ditches and laying linings of this class have commonly been followed with slight modifications of each, in Southern California.

The first, as illustrated by the full lines *A B I J* of Fig. 2, Plate VIII, is to form the ditch as a trapezoid in section—the sides sloping somewhere between 3 on 1 and 1 on 1, according to suitability in the material cut through by the excavation and used in raising the banks—and with the bottom level or nearly so across. In such sections the lining is first laid up as a wall, *A B C D E* and *F G H I J*, against each sloping bank, and afterwards, as a separate job, the bottom is paved, *C D G H*, between the wall footings.

The second plan, as illustrated by the full and broken lines *A b c d J* of Fig. 2, is to form the ditch excavation with sides on the desired slope, and join these sides with a rounded bottom whose curvature is so adjusted as to bring the slope lines of the sides of the finished water-way, *E e f g F*, about tangent thereto. In this form the lining is put in by first paving the bottom as an invert, and then immediately, as one job, extending this paving, as a wall, up against each sloping side.

The first plan of lining makes, unless considerable expense is incurred for its avoidance, a weak wall footing, and a broad expanse

of pavement, proportionately, to settle unevenly. From causes which will be apparent on a moment's reflection, cracks occur just on the line of junction of these two parts of the structure, and as the force of the water current and also the grinding action of the sands carried seem to search out these angles for special attention, failures are not infrequently traced to small beginnings here made.

The second plan necessitates laying the pavement first; and then the delivery of materials on and over it, and the unavoidable tramping upon it, causes cracks and uneven settlements; and there are other disadvantages attendant on construction under this plan that seriously affect not only the integrity of the result but the economy of handling the construction force. Moreover, this lining is so far interdependent all around the canal periphery that failure at any one part, near the bottom especially, is more apt to extend to the whole than in the case of work put in under the first general plan. And, finally, the stones used cannot greatly vary in size without making extra work to bring them to even bearings—the supply has to be carefully sorted over in gathering (see comparative sections, Plate IX).

Considering the two plans together, and remembering that the rounded bottom with side slope lines about tangent thereto makes a desirable form of water-way, it is plain that each has its advantages as well as disadvantages.

As will readily be understood upon reference to the cross-section, Fig. 8, Plate IX, also Fig. 1, Plate VIII, the Santa Ana Canal was planned for lining, so as to retain the advantage of building independently walled sides, and at the same time secure the benefits of a rounded bottom and avoidance of a weak corner in the section.

Referring to the diagram for a clearer illustration than words can convey, the excavation was made trapezoidal in section, but the lining was planned to produce a round-bottomed waterway. The walls were built so that about one-fifth in width of the desired bottom on each side was made a part of the wall footing, thus much thickening their base, throwing the lines of connection with the invert out without corners, and making good faces to which to joint the invert paving.

The plan may somewhat increase, over that demanded by either of the others, the amount of material necessary to line a ditch of any given capacity; but the process of laying is much bettered, and the result is believed to be a decided improvement, without necessary in-

crease of cost, over those heretofore attained, at least within the writer's knowledge, in lining large irrigation ditches with this class of material in Southern California.

To the engineer the plans of this class of construction will speak without further comment. But it must be remembered that it is no light responsibility to prepare for carrying 240 second-feet of water at a mean velocity of 5 ft. per second through soils that would melt away like fine sugar under its action if the canal lining should give way, and turn the flood down on to lands worth, where improved, over $1 000 per acre, as they are under some portion of the Santa Ana Canal in division III.

It will be observed from the section that stones of much variation in size can be used in lining by the plan adopted in this canal work, so that less care than ordinary had to be exercised in assorting sizes into the loads, and the larger stones find use where most needed—at the base of the walls. These walls were laid up in irregular layers over a long working face, the endeavor being made to bed every stone in mortar and fill every opening with spalls hammered into mortar. For economy this mortar filling was kept within the front two-thirds of the wall's thickness, the rear third and the space between the stones and the earth slope being filled with earth rammed into place, and slightly wetted to puddle and settle it.

The canal excavation was first made by contract, roughly (untrimmed), to the lines *A B C D* (Fig. 1, Plate VIII). This work was done by the use of ploughs and scrapers; the material was run out endways, for the most part with wheel scrapers, on runways left in or made for the purpose. It was not permitted to cut the banks to make runways, because this would result in uneven backing for the walls.

Just in advance of the wall building the slopes were trimmed down and wall footings excavated to the lines *A b c d* and *e f g D* for the two footings, respectively, leaving a central strip or core of earth, *c d e f*, between the footings, and making a decided foundation trench in which to set the base of each wall. This excavation work was done with picks and shovels, and the material was taken out of the canal with slip scrapers.

When it is remembered that the stones of this construction were rounded, water-worn boulders, for the most part without bedding faces, that they had to be split when necessary to secure such faces,

and that the work was done by common, unskilled labor, the desirability of having a footing bank and a foundation trench against and in which to bed the wall is readily understood as conducive to rapid and good work.

After the mortar in the walls had thoroughly set and hardened, the bottom was cleared and the necessary additional excavation, to the line *h i j*, was made with pick and shovel, to admit the invert paving between the wall footings. These stones were carefully and closely bedded, dry, in coarse sand, and spalls were hammered into such spaces as would admit them, to wedge the whole together. Coarse sand and fine gravel was then spread and swept with rattan stable brooms over the paving until the interstices became thoroughly well filled. The loose surplus having been swept out, the paving was left with the spaces between stones open, down nearly to the half-depth plane. Mortar was then thrown on and roughly shoveled and trowled in to about the level of and tops of the stones. After this had thoroughly hardened, the cement plaster lining was troweled on, first on the sides and last on the invert. To guide the work wooden centering frames were set at intervals of 16 to 20 ft., and lines were stretched between these by which to lay each course.

During all these processes due care was taken, by the free but judicious use of water, to make and keep the parts and work wet, so as to insure proper bond in setting. In the very dry air and scorching sunshine of summer in Southern California this necessarily constituted no small part of the cost of the work. The plaster, for instance, was kept wet for two weeks after troweling. The water was hauled in iron cylinder tanks on wagons drawn by four horses, sometimes a distance as great as 1¾ miles. Most of the stone was gathered in the wide torrent bed of Mill Creek, and the average haul was about 1 mile. The sand and gravel was hauled from Santa Ana River Cañon, an average haul of over 1½ miles, involving a very heavy pull up and over Morton Ridge, and most of it had to be screened before loading.

The mortar for the walls and invert was made in large boxes at intervals of about a quarter of a mile along the work, and then delivered in wagons, and subdelivered in barrows, where necessary, to the heads of chutes into the work. The cement mortar for the finish plastering was mixed in boxes on wheels carried close along the edge of the work, and run directly therefrom, in metal chutes, down to

PLATE XVIII.
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where needed. In all this work only common labor was used. It is true that a number of the men had some previous experience and training on work of this special kind, but they were in no sense masons or even skilled masons' helpers. Under favorable circumstances for work and under close and efficient superintendence, as good and cheaper results can be attained in this way, on a large work of this class, than by the use of skilled masons. It is found in Southern California that the higher paid class will, in spite of all that can be done in the way of supervision, be over-particular and slow with this ditch lining, and unnecessarily run up its cost very much.

In viewing this work it is well to remember that there are no soaking rains in this region, and, consequently, no surface or ground-water to lodge behind the sloping walls of the canal linings and spring them. If the canal itself does not leak, the earth through which it is excavated and against which its bank walls are laid will probably remain quite dry for all time. Nearly perpendicular banks of the red clay with boulders, 80 ft. in height, have stood from time immemorial in this section, never having received rainfall enough to wash them, though the soil gives way like sugar when a small stream runs over it for even an hour.

The rounded bottom of the completed canal section is part of a circle, with a 6½-ft. chord and 1½-ft. versed sine, and the sides rise from the ends of the curve, without being exactly tangent thereto, although nearly so, on slopes of 1 on ½, to a plane 6 ft. above the plane of the chord, thus making a total depth of 7½ ft. and total top width of 12½ ft. The full water plane is projected for 1 ft. below the top of the walls, thus giving a water-surface width of 11½ ft. and a water area of 52 sq. ft.

The earthwork was contracted for with a channel bottom width of 7 ft., and side slopes of ½ on 1.* This excavation was afterwards trimmed to receive the lining, as has been described. For all except one length of 275 ft. the walls have been built to a plane 2 ft. below the full finish, as shown at *J* and *K* of Fig. 1, Plate VIII; thus providing, fully, for the half capacity flow, as elsewhere explained. The location was so made that all the side wall, as at present built, rests in cutting. When the additional 2 ft. in height comes to be put on, much of the wall on the down-hill side of the work will rest against em-

* Grant Bros., of Los Angeles, were the contractors.

bankment. It was the intention to form this fill against lagging boards held in place by frames, a year in advance of the new masonry; and, in so doing, to wet and ram it, thus affording a uniformly good backing for all the lining work.

Cost of Lined Canal.—Excluding junction bay No. 7, there are 8 174 ft. of canal to the Alessandro pipe heading in division II. Of this, 483 ft. were in fills where box flumes were temporarily built in, thus leaving 7 691 ft. of channel which was lined. This length of canal is broken into 11 parts by the seven permanent and three temporary flume reaches, and thus there are 20 canal and flume connections made, of which six are with the temporary and 14 with the permanent flumes. The work done and kept account of under the head of "Connections" embraced in the aggregate about 82 ft. of the canal lining. The main part of the lining work, 7 609 ft. in length, was accounted for separately. One piece, 275 ft., of this was lined and finished to the full capacity height of walls as a sample. The balance was finished as heretofore described. The cost of this work was as follows:

Canal—Excavation, contract work	$8 583 52	
Bottoming and trimming, force work	2 667 56	
Total		$11 251 08
Side walls, in mortar	$12 764 38	
Invert, paved dry and sanded	945 22	
Plaster, covering invert and walls	3 696 20	
Total		17 405 80
Total		$28 656 88
Connections with permanent flumes		655 06
Temporary flumes	$599 15	
Connections with temporary flumes	102 25	
Total		701 40
Clearing up—Dressing banks, etc	$127 50	
Cleaning out canal	25 00	
Total		152 50
Grand total		$30 165 84

For the actual length of excavation—7 691 ft.—the earthwork cost at the rate of $1 46 per foot. Under the specifications the fills were built without cost over payment for excavation, so the canal channel

built—8 174 ft.—cost for earthwork $1 37 on the average per linear foot. Some of this work ran as low as 67.5 cents; in the heavy cuttings it exceeded $4, and the cost in normal cuttings was about $1.20 per foot of channel.

The 7 609 ft. of lining work accounted for separately cost at the rate of $2 29 per running foot, of which $1 67 was for the side walls, in mortar; 12.4 cents for the invert, paved and sanded; and 48.6 cents for the plastering of invert and walls.

The total cost per foot excavated, lined and accounted for separately was $3 75; the cost of lining per foot, plus the cost of channelway built, was $3 66. So, had the lining been put into the fills at once, leaving out the temporary flumes and connections therewith, the account for the work would have stood as follows:

Canal lined, 8 174 ft. at $3.664	$29 949 53
Permanent flume connections	505 00
8 174 ft. at $3.727	$30 454 53
Cleaning up and dressing banks	152 50
8 174 ft. at $3.744	$30 607 03

As it is, the summary was as follows:

Canal lined, 7 691 ft. at $3.664	$28 179 82
Permanent flume connections	505 00
Channel in fill, 483 ft. at $1.376	664 61
Temporary flumes	599 15
Temporary flume connections	64 80
8 174 ft. at $3.676	$30 013 38
Clearing up, dressing banks, cleaning, etc	152 50
8 174 ft. at $3.689	$30 165 88

Sand-Boxes.

Sand-Box No. 1.—On Plate VIII are shown plans of sand-box No. 1, located just 700 ft. from the initial point—the headgates' face. Partly hewn into a point of mountain, this may be described as a solid rock and masonry chamber. Within the wall lines it is 60 ft. long by 13 ft. wide, and its floor slopes transversely, so that its depth on the upper or hill side is 7 ft. 3 ins., while on the lower or cañon side it is 10 ft. 6 ins. The interior faces of all the enclosing walls are vertical.

While the floor slopes across to the outer wall, it is broken in

longitudinal profile by three transverse partitions, whose level tops are 6 ft. 6 ins. below the top plane of the main walls and are spaced at 15-ft. intervals from center to center and from the faces of the end walls. These partitions are 6 ins. wide on top, and their sides fall each way, longitudinally of the work, with a 2 on 3 slope. Against the face of each end wall of the structure the bottom rises again with a similar slope, and in the equivalent of one-half of one of the partitions. Thus, the bottom portion of the chamber is divided into four compartments, whose lowest parts, 30 ins. square each, are spaced 15 ft. between centers and lie next the base of the outer wall. To each of these sumps the chamber's bottom planes slope at the rates above given, and in each is located a sand valve which opens downward into a culvert leading to an out-fall on a sharp grade through the outer wall.

The top surfaces of the partitions are in the grade plane of the conduit, so that the sand-collecting part of the structure is in effect composed of four hopper-like compartments, each nearly half of a low, irregular, truncated pyramid inverted, and with the cut-off apex next the outer wall as a sump, in which is its outlet valve.

The flume connections are made through the end walls of this chamber on a line which leaves 1 ft. of clearance from the inner wall to the conduit's side, so that its center line, projected, is 3 ft. 9 ins. from and parallel with that face of the chamber. The inlet connection is a square cut-off of the flume by the chamber's wall, without flare, taper or rounding. But it is intended to change this, as elsewhere explained. The outlet connection is made by carrying the end walls around and the bottom surface up to the flume's opening, so as to produce an approach thereto approximating to the form of the *vena contracta.*

There will be a piling up and disturbance of waters in this chamber, so the walls are planned to a plane a foot above that of the sides of the conduit. It will probably be expedient to raise the flume sides 6 ins. to 1 ft. above the normal, for several bents beyond its intake from the chamber, to where the waters' full velocity becomes again established.

Not counting the sand-hopper space below the plane of grade and of the partition's tops, the water prism in sand-box No. 1 will be, for the half capacity, 39 sq. ft. in area, as against 14.1 sq. ft. for that of the flume. Conceding that it will operate evenly, this would reduce the

PLATE XIX.
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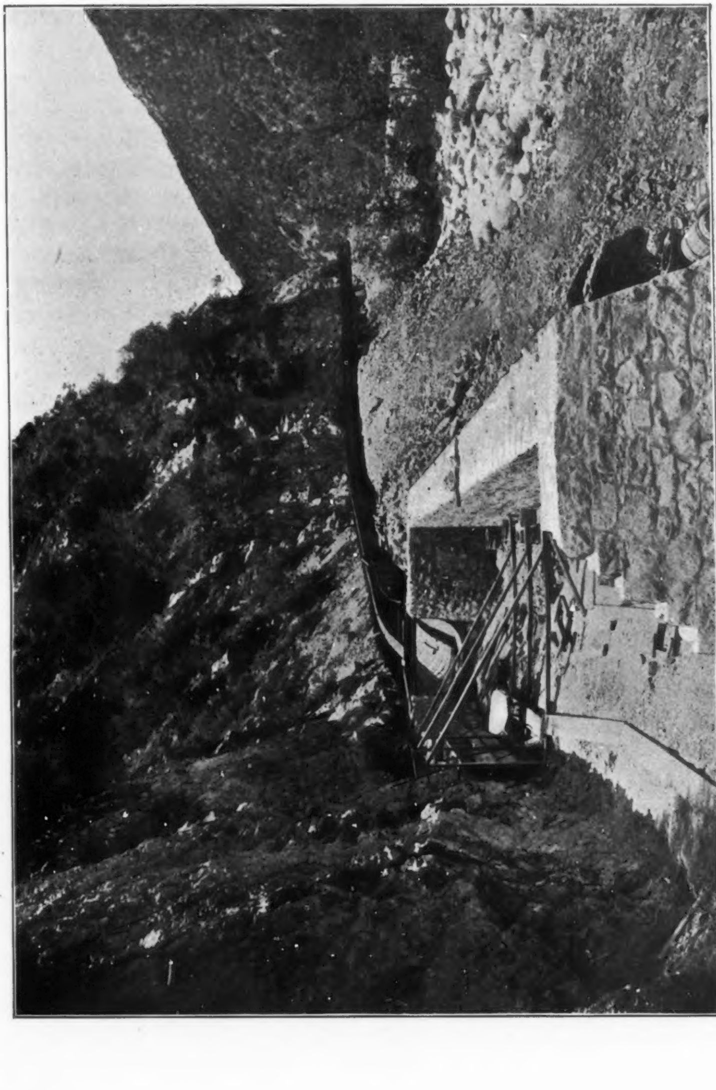


mean velocity from 8.52 to 3.08 ft. per second. For the full capacity the water section above grade in the sand-box will be 65 sq. ft. in area, as against 24.74 sq. ft. in the flume, reducing, in its turn, the current's mean velocity from 9.7 to 3.7 ft. per second. As will readily be understood, this chamber is not large enough to effect the precipitation of finer sands and sediments from waters which will pass through it. Even allowing for the influence of eddies, the mean velocity of water has to be brought down to nearly 1 ft. per second before it drops these lighter particles of its burden.

This sand-box No. 1 is intended to serve all requirements for a couple of seasons, but when the conduit comes to be operated to the full capacity of present finish even (though but half of the ultimate capacity), only heavy sands are expected to be stopped here.

A much larger and deeper settling chamber is projected for a point in the line several hundred yards lower down, and on which dependence is placed to clear the waters of their fine sands and sediments even when the full flow of 240 second-feet is being carried. At this lower point there is ample "dump" below the grade plane, to afford permanent clearance for sands in immense volume. At the location of sand-box No. 1 this dump and the fall away from it are not sufficient to insure the disposal of such a great volume of detritus as the finer sands and sediments of these waters would in a few years produce.

The sand valve used in this structure consists of a truncated, hollow, cast-iron cone with a projecting flange on its base. This valve, with the base down and the truncated end up, is drawn by its stem vertically upwards into the lower end of the short cast-iron cylinder, 18 ins. in diameter, which forms the sluiceway, and in such manner as to make a close joint between the flange base and the end of the cylinder sluice—these faces having been planed with that object in view. Sand settling in the space within the cylinder and around the cone-shaped part of the valve quickly stops all leakage. The valve opening squarely down, away from its bearing, cannot become choked if the outlet below is kept clear. For sand-box No. 1 the outlet culverts are about 36 x 24 ins. in sectional area, and the sluice cylinders and valves themselves are 16 ins. in diameter. The valve stem, of 1¼-in. round iron, passes loosely through the truncating cap of the valve, and is held to it by lock nuts underneath, within the cone. This stem passes up through a three-legged guide, cast in one with the cylinder sluice; and, thence,

parallel with the face of the chamber wall to a convenient level above the top thereof, where on its end is a hand-power operating wheel. Above the water line a heavy screw nut is held by iron brackets built into the wall, and through this nut the stem passes—itself being provided with the complementary screw of sufficient length to give the valve 20 ins. of movement. This motion is sufficient to drop the valve cone entirely out of the cylinder, so that its base may rest on the culvert's bottom; and, in this position, the escape area between the top of the cone and the edge of the cylinder sluice is nearly twice the area of the cylinder itself. This device has proved most effective and perfect in operation by several years' use in other sand-boxes of the Bear Valley Irrigation Company's works.*

The upper wall of sand-box No. 1 is 8 to 12 ins. thick, of concrete rammed into place behind mould boards and against the perpendicular face of the hard rock mountain base. The outer side and end walls are of rubble masonry; inner faces, vertical; top widths, 2 ft.; outer face batter, 4 on 1. The outer wall for about a third of its length rests on a base of concrete several feet thick, covering a low recess in shattered bedrock, to make the foundation uniformly good.

The entire structure is upon rock foundation, and with the natural rock backing for the rear wall above described. It occupies what was a sharp rugged point or reef of rock, around whose nearly vertical face the flume might have been carried on bench, or through which, by locating further into the hill, the conduit might have been carried in tunnel. Locating around the point, by flume, would have introduced into the alignment three additional curves—reversing twice—and necessarily of the minimum radius, in order to keep out of cut on the point, excessive for flume location, or avoid trestle supports each side of it. Either of these plannings it was desired for manifest reasons to avoid. Location through the point far enough back for a tunnel would have made approach cutting nearly as much in volume as was taken out for the entire sand-box excavation. The tunnel would have cost nearly as much as the sand-box, and would have been useful only as part of the waterway. A sand-box to take out the heaviest detritus which might pass the heading weirs was wanted as near the head as possible. This rock point presented the very first opportunity for the

* This sand valve is the invention of Mr. J. S. Black, C. E., whose services are hereinafter acknowledged.

outfall necessary from such a sand-box. Hence the determination to carry the work through the point, further back than a flume could have been economically placed, and not as far as a tunnel would necessarily have to be. This location made a first-rate alignment, cheap approaches and good benches each way for the flume, and afforded the opportunity for constructing a sand-box which would not rot out and give trouble. Here, then, we have the reason for constructing what may, without full consideration, seem to be an unnecessarily expensive feature in the work. Of course, a wooden sand-box could have been built several hundred feet further along in the work for less money, but to have kept the aggregate cost at less, the saving would have been made at the expense of a good location past the present sand-box point. No one sand-box would do the duty ultimately required. The one now built occupies the point of advantage for its purpose, and is an absolutely permanent work.

The excavation was carried uniformly down to the plane of the sloping bottom, because it was cheaper to do this than to cut out the hoppers separately, leaving the partitions between. After the enclosing walls were up, the partitions were laid in with dry rubble, well bedded and chinked, and over these and the rock floor a floor of concrete at least 4 ins. thick was rammed into place. The sluiceway cylinders are set in concrete. The sluiceway culverts are of rubble masonry in cement mortar. The entire inside of the sand-box and of the culverts is plastered with cement mortar—over all concrete and masonry faces.

The walls are thus far built to a plane 2 ft. below the full height, this corresponding to the half capacity finish. All the valves are in place, however, and the work is complete in all other respects. A timber staging has been thrown across from blockings on the walls, on which to fasten the screw nuts temporarily and to operate the valves.

Cost.—The work involved 410 cu. yds. of excavation, nearly all rock and much hard rock, which was done with special care in order to save natural walls and an unshattered bottom, at a total cost of $352 10, or 86.3 cents per cubic yard. There are in the structure 160 cu. yds. of uncoursed rubble masonry in cement mortar, including the culvert arches and inverts, which cost $1 242 40, or $7 76 per cubic yard, and 540 cu. ft. of concrete put in at a cost of $178 50, or 33 cents per cubic

foot, and 30 yds. of dry rubble filling cost $31 50, or $1 05 per cubic yard. The plastering 2 115 sq. ft., cost $96 35, or 4.5 cents per square foot. The gates, put in, cost $148 66, or $37 16 each. The staging cost $41 05, and sundries, $27 45, brought the total cost to $2 118.

Junction Bays and Connections.

As planned, between the intake and the delivery to the Alessandro pipe line there are 45 structures, besides those serving merely to unite others. As each structure is different in character, formation or form from both that which precedes and that next below it in the line, there were 44 connections to be made. Four of the 45 structures, namely, two wasteways and two sand-boxes, have temporarily been omitted; and, hence, the connections now made are 40 in number.

To effect six of these, namely, those at each end of the pressure pipe lines, it was necessary to design special works, which cost no inconsiderable amount; and these are herein called junction bays. Two lead from flumes into pressure pipes; one, from pipes to flume; one, from tunnel to pipes; and two, from pipes to tunnels. They have all been constructed to full-capacity finish for the passage of 240 second-feet of water, and are of boulder rubble masonry in cement, with concrete bottoms, except one of the last two—that which joins Morton Cañon pipes to Morton Ridge tunnel. This was designed for concrete and iron, but was built for present use of timber upon a concrete foundation, and is really more in the nature of a penstock than of a junction bay, as the word is herein used. These special structures are all in division I.

In division II, eight of the connections between distinct parts of the waterway required radical treatment, and seven others of another character demanded much work in addition to any equal length of aqueduct either way from them.

But all of these were merely gradual mergings of one form and construction of waterway into another, without the intervention of distinctly different structures. These are brought to the half capacity finish only, though it would have cost but little more, proportionately, to complete them for passage of the full 240 second-feet. The following table gives a comprehensive idea of the extent of this subject and furnishes briefly a key to the manner in which it has been dealt with.

Connections of those classes in the table on page 135 lettered "A" are

at points of but slight change in either form, size or structural character of the aqueduct, and are made by joining the walls of the construction on gradual lines of merging, and plastering thereon along taper slopes set out by a straight edge without any special plan, but so as to avoid even the appearance of any offset or obstruction to the current's flow.

JUNCTIONS AND CONNECTIONS.

Class of Treatment.	Where Placed.		Number Designed.	Number Made.
	Out of.	Into.		
A.	Tunnel	Walled canal	1	1
B.	"	Flume	6	6
I.	"	Pressure pipe	1	1
H	"	Lined canal	1	1
B.	Walled Canal	Flume	1	1
C.	Flume	Sand-box	3	1
B.	"	Wasteway bay	3	3
B.	"	Tunnel	2	3
I.	"	Pressure pipe	2	2
D	"	Lined canal	6	7
I.	Pressure pipe	Flume	1	1
I.	" "	Tunnel	2	2
E.	Lined canal	Flume	6	7
A.	" "	Wasteway bay	1	0
E.	Sand-box	Flume	1	1
F.	"	Wasteway	1	0
G.	"	Lined canal	1	0
A.	Wasteway bay	Tunnel	4	3
E.	" "	Flume	1	0
			44	40

Those of the classes lettered "B," found in division I, between flumes and masonry structures whose waterways differ but little from them in cross-section, are made by lapping the flume about 2 ft. into the structure joined and filling with concrete and mortar the space in the lap around the flume shell. This filling is made against form boards on the outside end, to effect a wall-like facing, and is carried away on long slopes, put in by a straight-edge, without a drawn plan, inside of the concrete lining or masonry, so as gradually to effect the change of form and dimensions between the flume waterway and that of the structure joined. And, finally, these sloping faces of concrete are plastered so as to bring the surfaces neat to the flume's inner edge without shoulder or offset.

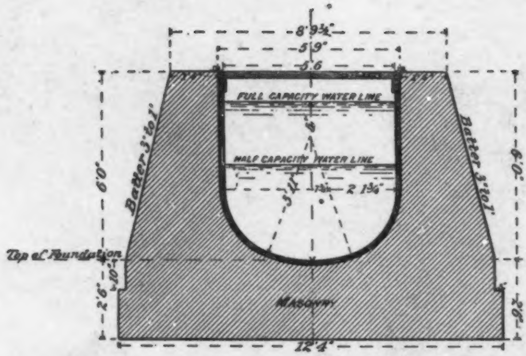
The joinings lettered "C," those out of flumes into sand-boxes are planned to spread the flume in 16 ft. of its length to near double

its normal area and to receive it between wing walls from the masonry structure, spreading still more, so as to introduce the water to the chamber at the full width of the latter; the mechanical work of the junction between the wooden flume shell and the masonry walls to be substantially the same as that described last above. But one junction from a flume to a sand-box has been built; and in the haste and enforced economy of finishing the work for immediate use, the flaring part was omitted and the connection made by the flume at normal section in a rectangular end wall of the sand-box. This should and probably will be changed before the works are used to full capacity (see Plate VIII).

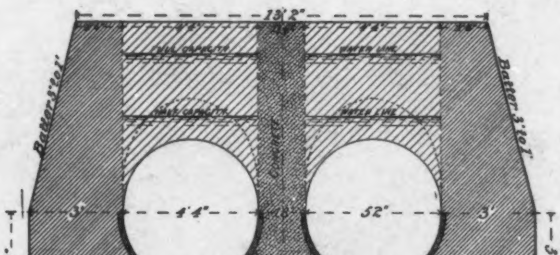
Class "D" junctions are from flume to lined canal sections in division II. Here the change of size and form of waterway is radical, but it is from a smaller to a larger section. The flume shell at normal size is joined in the manner above described into a cut-off wall of masonry built squarely across the canal section; and then the transition from the flume to the canal section is made somewhat gradual by a concrete filling laid within the canal section, as shown by a figure on Plate XX, and the interior surfaces are brought smoothly together in plastering, as explained for connections of the two preceding classes. The extra work at these connections is all within about 12 ft. of the running line.

Connections of class "E"—the reverse of those of class "D"—are at points of reduction of the waterway from the larger masonry sections to the smaller wooden section of the flume. The change of form and size of waterway is made, gradually, in 24 ft. of length, of which 16 is of flume and eight is canal lining work; and the mechanical junction between the two is made in the manner heretofore described within return walls of masonry ending the canal work (see Plate XX). The staves for these connection taper lengths were all worked to and set up in a trial form in the company's yards, the iron bands were there bent and threaded, and the wooden sills and bolsters put together, so that erection in the field was much simplified. Trouble was at first experienced by the binding rods creeping down along the taper as they were drawn tight, but this was soon obviated by the chock pieces shown.

The one connection of class "F" thus far planned—from the wooden sand-box to masonry wasteway—has not been constructed.

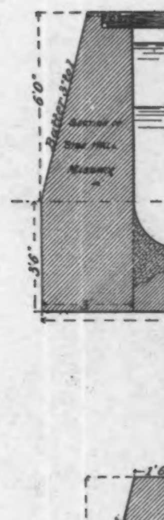


SECTION ON LINE I-J

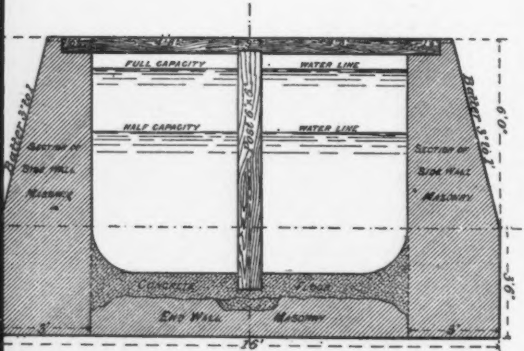


SECTION ON LINE G-H

J

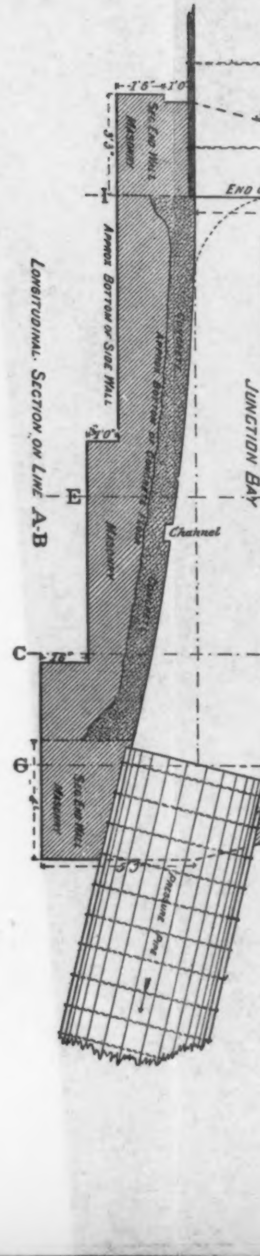


PLAN AND SECTIONS
JUNCTION BAY No 1
DIVISION I



SECTION ON LINE C-D

SECTION ON LINE E-F



LONGITUDINAL SECTION ON LINE A-B

PLATE XX.
TRANS. AM. SOC. CIV. ENGRS.
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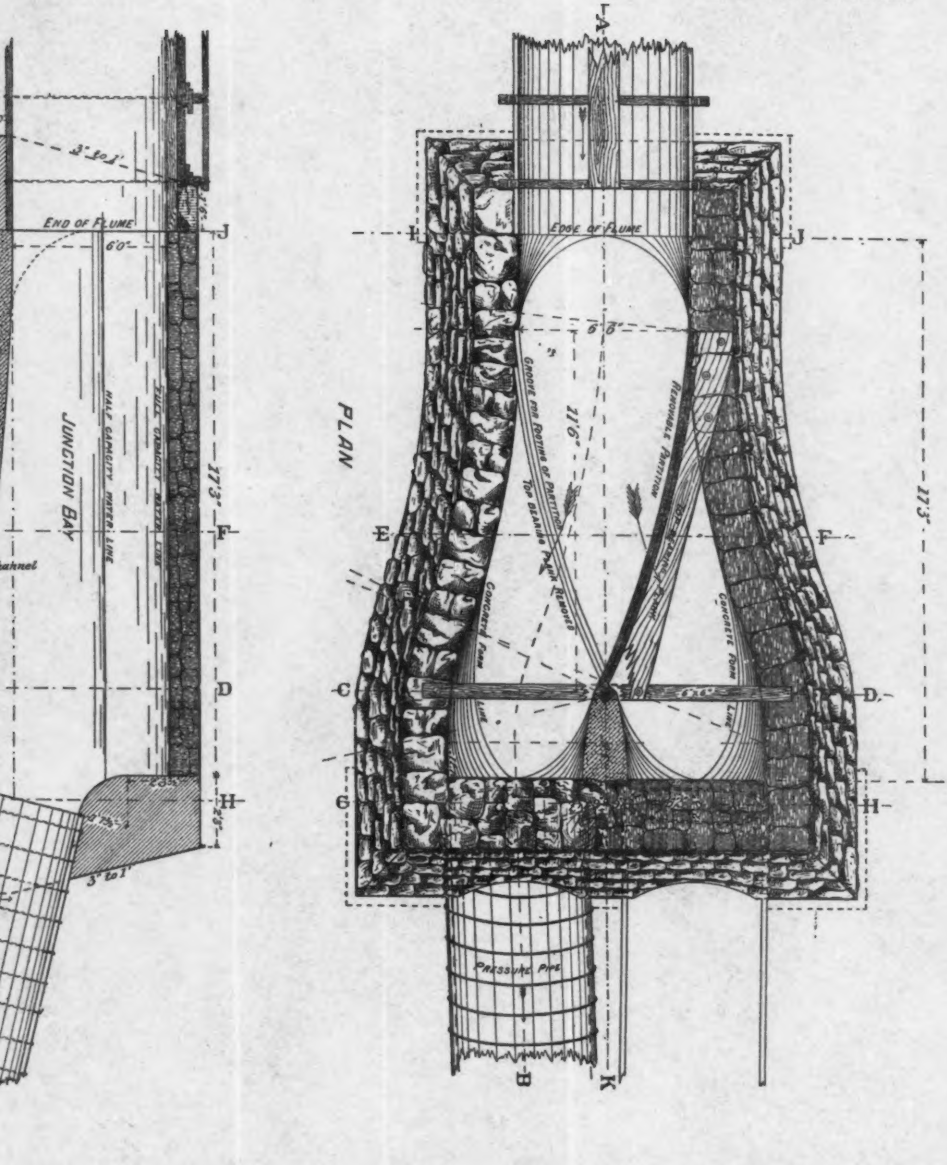
HALL ON SANTA ANA CANAL.



In form its plan is substantially the same as that next preceding, but is reversed in the order of materials used, being from the larger wooden to the smaller masonry section. The one connection of class "G" designed is not yet constructed, being from sand-box to walled canal.

Type "H" has its single exemplification in the connection between the submerged tunnel and the lined canal, and is illustrated by figures on Plate IX, Fig. 10. It is a simple enlargement and deepening of the canal section back to the tunnel portal wall, and is built precisely the same as the canal itself, except that the walls were made heavier at the base as they became higher. This connecting link occupies 40 ft. in the length of the line, and is scheduled as junction bay No. 7.

Plans for a typical masonry junction bay—type "I"—are shown by the figures on Plate XX. They represent the structure built at the upper end of the Warm Springs piped crossing, and known as junction bay No. 1. There are five in all, quite similar to this one, completed on the work.

All of these are of boulder rubble masonry in cement mortar. They were built by carrying the walls down to suitable foundations all around, leaving a core of less firm material on the inside at a plane about 8 ins. below the desired bottom grade, and then forming the bottom within the walls with concrete. Some of the foundation excavations had to be carried as much as 6 ft. below the grade planes of the structures themselves, but generally the wall bottoms are 2 to 3 ft. below the floors. All rest upon rock or indurated clay. The flumes and pipes are built into the walls from 1 ft. 6 ins. to 2 ft. 10 ins. in length, and the joinings made in cement mortar. The entire chamber is plastered with cement mortar as described for tunnel finish work.

Plate XX shows plan and longitudinal and cross sections of junction bay No. 1. It is 17 ft. 3 ins. long by 10 ft. 3 ins. greatest width between walls, and its foundation covers a space 24 ft. 3 ins. x 16 ft. 6 ins. Its front and highest wall—that into which the pipes are built—is 11 to 13 ft. high from foundation to crest; interior face, vertical; top width, 2 ft. 3 ins. at 1 ft. above the full-water plane; exterior batter, 3 ins. to the foot, for 6 ft. down to canal grade, where its thickness is 3 ft. 9 ins., and thence vertical to foundation. The back and side walls have top widths of 1 ft. 6 ins., and outside and inside faces the same as the front wall. The lowest, the back wall, which receives

and holds the flumes' shell, is 8 ft. 6 ins. high and 12 ft. 4 ins. across the structure on the foundation line.

The pipes, which are bolstered only 6 ins. apart in the main part of the crossing, are spread to 16 ins. apart where built into the walls of these junction bays, as shown in plan of No. 1, and are cut squarely off and the masonry rounded to them on top, as shown in the section of the end wall appearing in Fig. 2. Between the openings of the two pipes is a concrete partition, projecting from the front wall 3 ft. 6 ins. into the chamber, dividing its end next the pipes into two bays—one for each pipe. This partition is built up from below the floor—out of which it comes—monolithic to the plane of the top of the structure. Its up-stream edge or point is made of a 6 x 6-in. timber built and bolted into it. A tie beam, 6 x 6 ins., caps this timber, extends across the top of the chamber, and is here built at each end into the side wall. This tie beam and the vertical timber post give to the partition whatever strength it may lack to resist lateral thrust when the waters are confined to one side and pipe only, and take the thrust from the removable partition next described.

From the point of the concrete partition, diagonally and curving, as shown in the plan, up stream to each side wall at a point 3 ft. from the flume's entrance, a square-down groove, 4 ins. wide and 3 ins. deep, is made in the concrete of the floor. Two 4 x 14-in. timbers resting on the cross-tie and on the walls and bolted thereto, one above each groove, have their up-stream edges curved to correspond to the curve of the groove below and to set vertically over its outer edge. The groove and these timbers serve as the lower footing and upper bearing, respectively, of vertical 2 x 8-in. needle boards, set in double row lapping seams, like sheet piling. These, extending from the partition's point to the wall and lapping on to each, as shown, form a gate or controlling partition which may be placed in either bearing at will. The form of each, approximating to the curve of the opposite wall, as tending to keep the water passage of even width, will be observed.

In laying the concrete bottom the plane along these grooves was kept free from transverse curve, having the slight longitudinal vertical curve only. Thus, from the upper point of the partition's rest against the walls down to the section *E F*, the chamber bottom is level across and the sides vertical. Above the partition's upper end the corners of

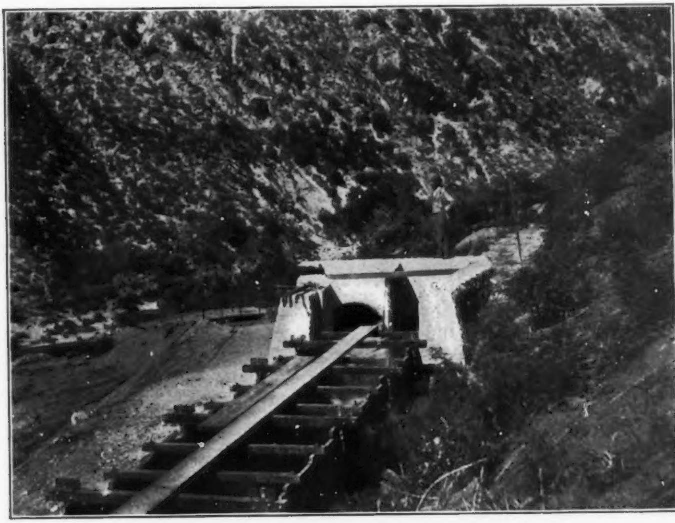


FIG 1.

FIG. 2.

the chamber are formed with concrete rounding to the flume form. Below section *E F*, next the outside wall and below the point of the central partition, the chamber's bottom is rounded in the corners by the concrete work and gradually brought to the forms of the pipe bottoms in the two pipe bays.

It is not at all likely that these partitions will be used more than once a year at each piped crossing, to effect clearance of one pipe while the other is in use, unless in the case of accident, and hence it was not thought necessary to design gates admitting of greater ease of operation than do the vertical needle boards.

In this design five points may be worthy of notice—(1) that when in full operation the waters are gradually spread from the flume and are diverted to the two pipe bays by a thin-edged partition, and that the chamber throughout is formed to avoid disturbance of the flow; (2) that the space in the succeeding cross-sections of the chamber has been kept, as near as practicable, commensurate with the duty to be performed; (3) that the structure itself is made, in longitudinal profile, to serve as a downward curve in the waterway, thus enabling the pipe to lead away on a tangent of down grade therefrom; (4) that by this means, also, the pipe intakes are placed in grade, so that the half flow water plane in the flume will submerge and put the requisite entry head over either one separately; (5) that the operation of either pipe by itself is facilitated by the form of closing partition, or gate, which can be placed to guide the waters smoothly and without obstruction into either of the pipe bays.

Junction bay No. 2, at the other end of the Warm Springs pipes, is almost precisely the reverse of No. 1, except that the structure as a whole serves, not only in vertical curve to join the pipes upward gradient at the flume grade, but also in horizontal curve to join the alignments of the two. The introduction of this horizontal curve into the junction bay greatly relieved and simplified the location of pipe and flume, respectively, each way therefrom.

Bay No. 3, at the upper end of the Deep Cañon pipe crossing, is the same as No. 1, except that the pipes lead out of it horizontally and then curve down. Bay No. 5 joins the lower end of tunnel No. 8 with the upper end to the Morton Cañon pressure pipes, and out of it the pipes lead at a descending angle considerably greater than that shown in the plan for No. 1. Otherwise it is about the same. Bay No. 4

joins the lower end of the Deep Cañon pipes to the upper end of tunnel No. 8. Into it the pipes rise on a grade much steeper than where junction is made with No. 2. In other respects these two are substantially the same.

The wooden penstock at the point of joining the Morton Cañon pressure pipe with the submerged tunnel through Morton Ridge is classed with the masonry junction bays only because it is a special connection structure. In design and construction it is radically different from them, for the problem presented at this point was different from any other on the work, to join two wooden stave pressure pipes, 52 ins. diameter each, to one wooden stave tube, 72 ins. diameter, at a point over 16 ft. below the hydraulic grade line; and to preserve them free to access and provide for closing off one pipe while the other should be in use.

The junction work was designed as a monolithic concrete tower of the requisite height—coping of walls 19 ft. above tunnel grade—rectangular in plan outside, and having an oval-shaped well inside. The axial diameters of the well down to the gates' bearing shoulders were to be 6 ft. and 9 ft. 6 ins. lengthways and across the direction of the aqueduct, respectively; and the outside dimensions 8 ft. x 11 ft. 6 ins. at the top, and 10 ft. x 13 ft. 6 ins. at the foundation line. The concrete was to be put together with old steel cables embedded in it, spirally around, to give the walls tensional strength. The plan shows a square cut-off for the pipes inside the well along the face of a concrete shoulder setting 2 ft. 8 ins. into the oval, and iron gates operated from above with power gear, one for each pipe, in runners set in the face of the bearing shoulder, and fitting on to seats over the pipe openings.

In place of this permanent structure there stands a heavy timber penstock of good workmanship, everything being mortised, tenoned and well fitted, and held together by bolts and rods, and resting on a concrete foundation. This chamber is 4 ft. x 9 ft. 6 ins. in plan and 17 ft. 6 ins. deep, inside. The timbers are 6 x 6 ins., 6 x 8 ins. and 8 x 8 ins.; and sills, 8 x 12 ins.; the plank, 2 ins., and the tie rods 1 and $1\frac{1}{4}$ ins. diameter. Provision for wooden gates is made. For the period of its life such a structure will do well enough, but the writer's experience is that wooden-framed structures have very short lives in hydraulic construction in California. Under ordinary circumstances

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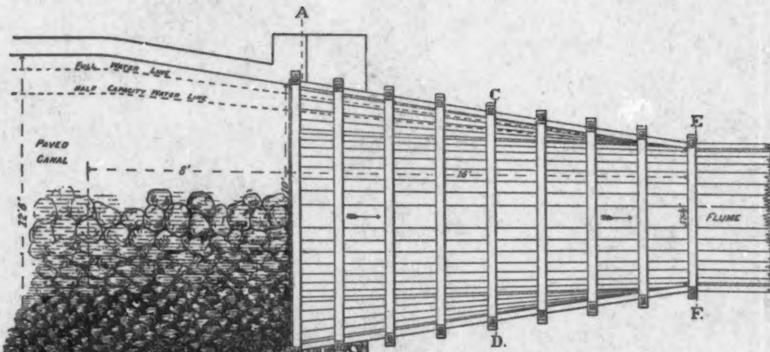
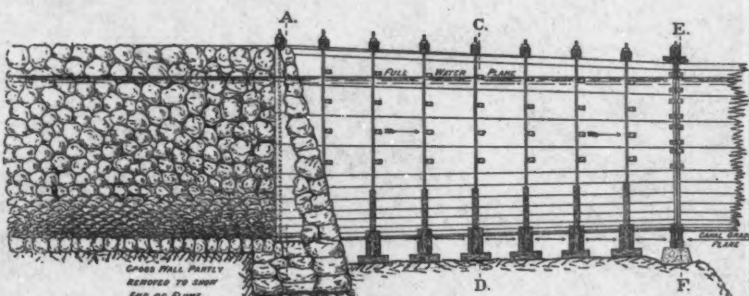


PLAN: REDUCING CONNECTION.



SIDE ELEVATION: REDUCING CONNECTION.

PLAN AND SE
CANAL AND FLUME
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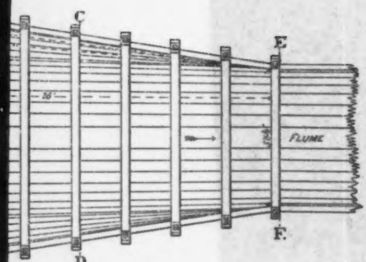
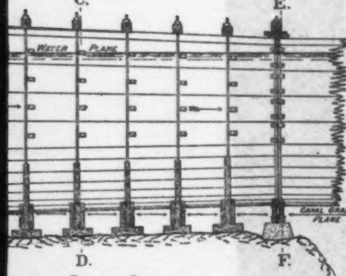


AN: REDUCING CONNECTION.



LEVATION: REDUCING CONNECTION.

SECTION: RE

PLATE XXII.
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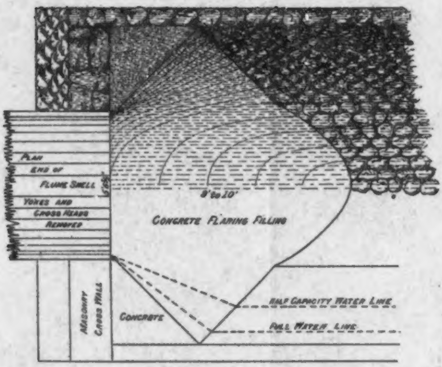
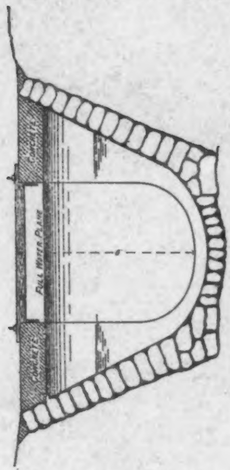
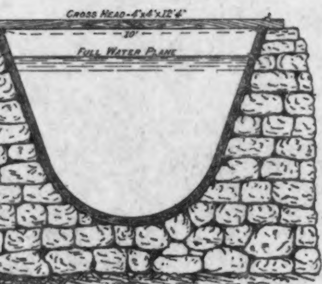
...LAN AND SECTIONS
...L AND FLUME CONNECTIONS
DIVISION II



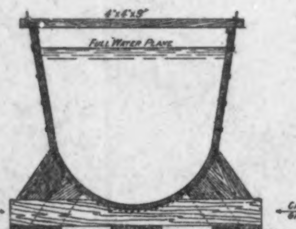
PLAN: ENLARGING CONNECTION



END VIEW ENLARGING CONNECTION

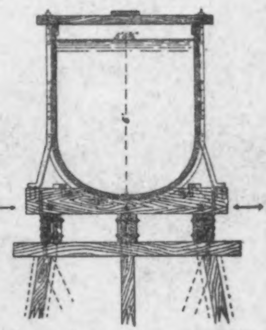


SECTION: REDUCING CONNECTION AT A-B.



SECTION: REDUCING CONNECTION AT C-D.

THESE CROSS SECTIONS ARE DRAWN IN THE PROPER POSITIONS RELATIVE TO THE GRADE PLANE.



SECTION: FLUME, ON TRESTLE BEYOND E-F.

the writer thinks it would be a mistake to build this penstock, but circumstances were such on the Bear Valley Irrigation Company's works at the time it was put in that there was no alternative. The lines of junction of the two pressure pipes with the one tube of the tunnel section are shown by figures on Plate XXII, and this subject, in other phases, is elsewhere referred to. The timbers of the penstock are of Oregon pine and the sills and plank of redwood. All seams were calked with oakum and payed with hot asphalt.

Cost.—No separate account was kept of the extra cost at connections in classes A and C. It was insignificant and not segregable. Those of class B, between tunnels and flumes and other masonry or concrete-lined structures differing but little from the flume in section, cost from $5 to $12 each, according to locality and amount of concrete and mortar required. Those of class D, the entrances of flume into the larger lined canal sections, cost, on the average, about $42 each, of which about $32 to $34 50 was for the masonry cross-wall, and $7 50 to $10 for the concrete filling inside the canal lining. These amounts represent costs, in addition to the canal lining work proper, which latter would thus embrace the plaster finish over the concrete. Connections of class E—the contractions of lined canal into flume sections—cost, on the average, about $71 25 each, of which $27 75 was for the masonry cross-wall, and $43 50 for the 16 ft. of reducing flume in place. This leaves the canal lining, including slope walls, invert and plaster, for the 8 ft. of reducing section in canal construction, to be covered by cost of canal work, as elsewhere shown.

The one connection in class H—from the submerged tunnel to the head of the lined canal—scheduled as junction bay No. 7, and embracing 40 ft. of the running line, cost $432 50, which is segregated about as follows: Excavation, contract work, $50 40; trimming out, force work, $15 40; end wall, concrete foundation, $60 10; masonry, $128 50; lining walls, $72 25; invert paving, $5 25; finish, plaster, $28 65; gate, $14 90; back fill on lower side and shaping banks, $42 05; sundries, unapportioned, $15 20. The paving, side walls and plaster, were averaged with all the canal work of those classes, as elsewhere appears.

Connections of class I, at the ends of the pressure pipes, junction bays Nos 1 to 5, inclusive, those of masonry, cost as follows: Excavation of foundations, $70 35; walls, masonry, $2 616 79; floors and shaping interiors, concrete, $204 61; finish, plaster, $130 77; woodwork,

$112 02; total, $3 134 54; average, per structure, $626 91. In addition to this, there are charges of $883 31, for contract grading of approaches to tunnel No. 8, in which junction bays Nos. 4 and 5 are built, and also $99 60, force account grading, in the aggregate, at the five sites. These grading costs, however, though properly charges against the sites, are not set against the structures as such. The cheapest of these bays cost $556, the average of the two at the Warm Springs Cañon crossing; and the most expensive, that at the north end of the Deep Cañon pipe, cost $714; both inclusive of foundation excavations, but not of the grading above the plane of the flume grade at the sites. Why the latter cost so much the more, though it had less work in it, is elsewhere made plain.

Junction bay No. 6, the wooden penstock, with some outside work, cost $403 20; of which $54 60 was for the concrete foundation, inclusive of excavation therefor, $336 20 was for the penstock proper, and pipe and tunnel connection therewith, and the extra work in the 16 ft. of tunnel lining made to flare to an oval at the penstock joining, and $12 40 was for drainage at north end of the tunnel and under the penstock, to provide for possible leakage. At this site also, there is a charge of $128 for grading the tunnel approach wherein the bay is built.

Wasteways.

Two kinds of wasteways are among the structures on the Santa Ana Canal. The first is a sluiceway for turning out the waters of the aqueduct in a body through one or more gate openings. The second is in the nature of a spillway for wasting waters in a long sheet over a lip provided in the side of the aqueduct.

The first plan necessitates the action of an attendant to open a sluice gate before it becomes operative. The second is within limits, self operative, by waste commencing over the spillway lip when waters rise to its level. Works by the first plan are built in division I. The second design was made for division II. In division I the advantageous point of the second design is secured in connection with the first, by wasting waters over the side of the flume fixed as a spillway.

A wasteway, No. 1, is at the intake, as hereinbefore described with those works. Below that there are five planned in division I, and one in division II. Four in division I are at the upper ends of tunnels Nos. 3, 4, 5 and 6, respectively, spaced about 3 200, 6 350, 8 840 and

12 930 ft. from the intake. Two of these are completely built, the other two have only their stop-gates in the aqueduct built, and are operated to effect waste over the flumes' edge. The next one is planned for the lower end of tunnel No. 8, a distance of 17 000 ft. from the head, but is not built, a temporary wasting flume having been placed there for present use.

Of those built, or partially built, the following is a type. In the opening of a masonry portal at the up-stream end of a tunnel a gateway frame is built flush with the face of the waterway—the end of the roof arch being kept back of the end faces of the side walls sufficiently to admit the operation of the gate, in the grooves of the frame, in front of it. This constitutes the stop gate. At present simple flashboards are used for these gates, but the plans call for a channel iron frame gate, moved in the grooves by overhead gearing, within which frame the gate is completed by removable flashboards. This arrangement permits its use as a sluice, by operating the whole frame by means of the gearing, or as a regulator, by keeping the sliding frame in place and removing one or more flashboards from it as may be desired.

Extending the waterway in the same form and size as that in the lined tunnel, a masonry bay is built 18 ft. in length up stream, and into the upper end of this the flume is connected. The outer wall of this bay is made of three masonry piers, each 2 ft. 6 ins. long in the direction of the aqueduct, by 6 ft. wide on the base, and 6 ft. high above grade, and between these piers are two gateways, 5 ft. 6 ins. opening each, with runways built into the masonry. The form of gate above described for the stop-gate is designed for use in the outlets; but here, also, only wooden flashboards are as yet in place. In this position the permanent gates will admit of operation either as under sluices or as weirs. The design provides for setting the outlet gates in iron runners flush with the inner face of the masonry of the piers, thus completing the chamber as a portion of the aqueduct without material obstruction to the water's flow along its side.

In connection with this form of wasteway, by adjusting the flume plank on the outer side to the desired height of water flow for several 16-ft. lengths above, provision is made for a spillway, operative when the stop-gate is sufficiently closed, or when water is running deep enough in the aqueduct. This form of spillway is illustrated in operation on Plate XXI, Fig. 2.

Wasteways of this class have been located at the upper ends of tunnels, because the spacing happened to come about right in the line, and because at these points hard-rock foundations and backings could be had for the masonry, thus insuring its stability with least volume and cost. Moreover, the opportunities for spilling the waste waters over hard rock and conducting them harmlessly back into the river under these points were specially favorable.

Wasteway No. 5, the lower one of the four just referred to, is also to serve as the outlet for waters that are to be dropped from the Santa Ana Canal to the company's Bear Valley and North Fork canals, as elsewhere referred to. The outlet at this wasteway is into a flume which extends about 100 ft. around the face of a rock point to the head bay of the power drop pipe, and provision is made for wasting the whole or any portion of the canal's volume of flow out of this flume sideways down a rock gorge which has a fall of 330 ft. vertical in about 550 ft. horizontal distance to the main cañon bed.

The necessity for these frequent wasteways will be the more apparent when we reflect that an accident at any one of a number of places along the route of this work might be very disastrous to the aqueduct itself, owing to comparatively poor material under its foundations being washed away. This would be the case in the cañons at the pipe crossings especially. Hence, the desire to provide outlets at points easy of access where the patrolmen could quickly divert the full volume of flow, pending its being closed off at the head. All the points of waste are well situated with this object in view, except that at the head of the long tunnel, No. 5; and it is proposed to provide for the operation of this stop-gate from the lower end of the tunnel by means of a cable through it, and to make a long flume edge spillway above it. As elsewhere explained, accidents are to be anticipated consequent upon landslides and boulders rolling from the mountain side above.

Wasteway No. 7 is designed for the lined canal immediately above its junction with the flume crossing of Mill Creek. The object is, by the operation of a combined drop and flashboard gate, placed in runners at the head of the flume, to be able to regulate waste over a spillway, and even effect the full relief of the canal by this means without opening waste gates. The form of canal is not altered in this spillway bay, only that for 100 ft. in length next above the stop-gate the spillway lip is kept at the level of full water flow in the canal so that any

check of the flow by the stop-gate will cause wasting over the full length of the lip. To this end the canal bank on that side is built in masonry, and at the top it simply rolls over, forming the lip, into the side wall of a parallel canal, which is the wasteway channel. The escaping waters here will go diagonally and at a small angle of deflection out of the aqueduct over a lip, just as they come into it at the heading.

Cost.—The combined cost of wasteways Nos. 2, 3 and 5, finished for use as above described, was $561 37. Of this amount $45 60 was for foundation excavation, $390 10 for masonry, $25 37 for concrete, $29 70 for plaster finish, $40 42 for woodwork and gates, and $30 18 for unapportioned expenses. These structures all set in tunnel approaches where the sites were for the most part graded by contract work; but these gradings have been included in the general cost of the flume bench, as elsewhere shown. Besides this, $159 90, force account grading, is charged against the wasteways, principally No. 5, for the bed on which to locate the waste flume; and this flume itself cost $65, making a total of $786 27, of which $484 60 was for No. 5; $104 87 for No. 3, and $196 80 for No. 2.

In addition to the above, there were expended $149 20 for a bench and waste flume leading from the site for wasteway No. 6 to an available point of discharge, together with a connection of the same with junction bay No. 5 for temporary use. This item brings the total expenditure, under the heading of wasteways, to $935 47.

Power Drop.

As illustrating a valuable feature of this enterprise and one of special utility, the proposed power drop may be mentioned. The company already has two canals in operation, which derive waters from the Santa Ana River at its cañon opening several miles below the heading of the new work. The total delivery which will ultimately have to be made to these works will be between 50 and 60 cu. ft. of water per second. The new canal on the mountain side above commands the highest of these lower diversions, and with about 350 ft. of fall to spare within a horizontal distance of a little over 700 ft. Between the new point of diversion and the lower ones, at times of least water flow especially, there is great proportional loss of water in the river channel. Evaporation, as the water tumbles over and

spreads around the hot rocks and gravels of the cañon channel, is intensely active; and for months succeeding storms which have disturbed the channel gravels the loss of water into the boulder bed is still greater.

The double purpose of saving waters thus lost and of acquiring the power head prompted provision for diversion for all the canals together at the new intake and the introduction of the proposed drop. Of course, the drop will be effected through pipes, and there will be available, on the 50 second-foot basis, about 2 000 H. P., gross.

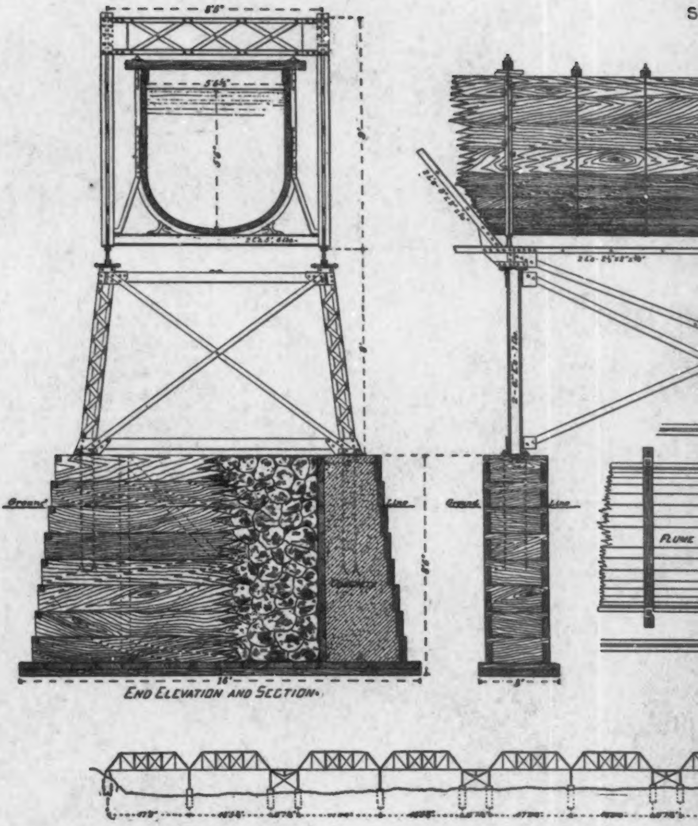
As, owing to great variability of water flow in this work at different times of the year, the available power will run down as low as 200 or 300 H. P., the proposition is to apply only so much as is reasonably constant to such uses as will require a nearly continuous service, and to apply the balance, when at hand, in pumping additional waters for irrigation either out of the gravels of the cañon near the point of generation or by electrical transmission in the valley below. The great value of irrigation waters in this region, and their scarcity compared to growing demand, will justify this utilization, and make it a valuable accessory to the main enterprise; for the power available will be greatest during the months when irrigation waters are most in demand.

Mill Creek Steel Bridge.

The aqueduct across Mill Creek torrent consists of a flume of the character already described, carried through a riveted steel bridge resting upon steel piers with concrete foundation piers. The bridge consists of 19 Pratt spans, 48 ft. each, put up in couples, with a rocking pier at point of junction, alternating with 10 Fink spans, 16 ft. each, in the intermediate braced trestle piers. Total length, 1 072 ft.

Excluding the end abutment walls, there are 28 pier foundations, which are built of concrete in 2-in. plank casings, carried from 6 to 10 ft. down into the boulders of the wash. The end or abutment bearings are of rubble masonry in cement mortar.

Plate XXIII illustrates the principal parts and some details of this bridge. Attention may be drawn to the form of foundation piers as securing connected pier foundations with a small amount of concrete. Observe that the concrete is limited to the compartment of the casing, at each end immediately under the truss bearings, the intermediate compartment being filled with loose cobbles and gravel.



8'8"
5'6¾"
FLUME
END ELEVATION AND SECTION.

MILL CREEK STEEL BR
SUPPORTING
STAVE AND BINDER FL
DIVISION II

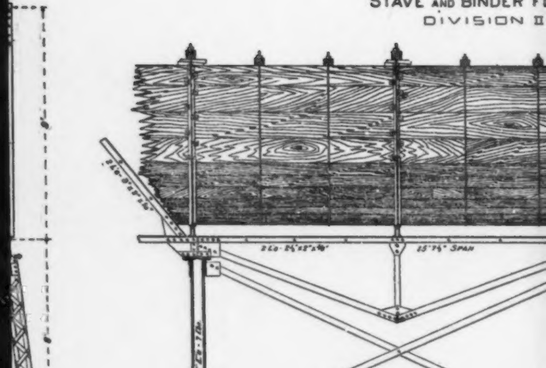
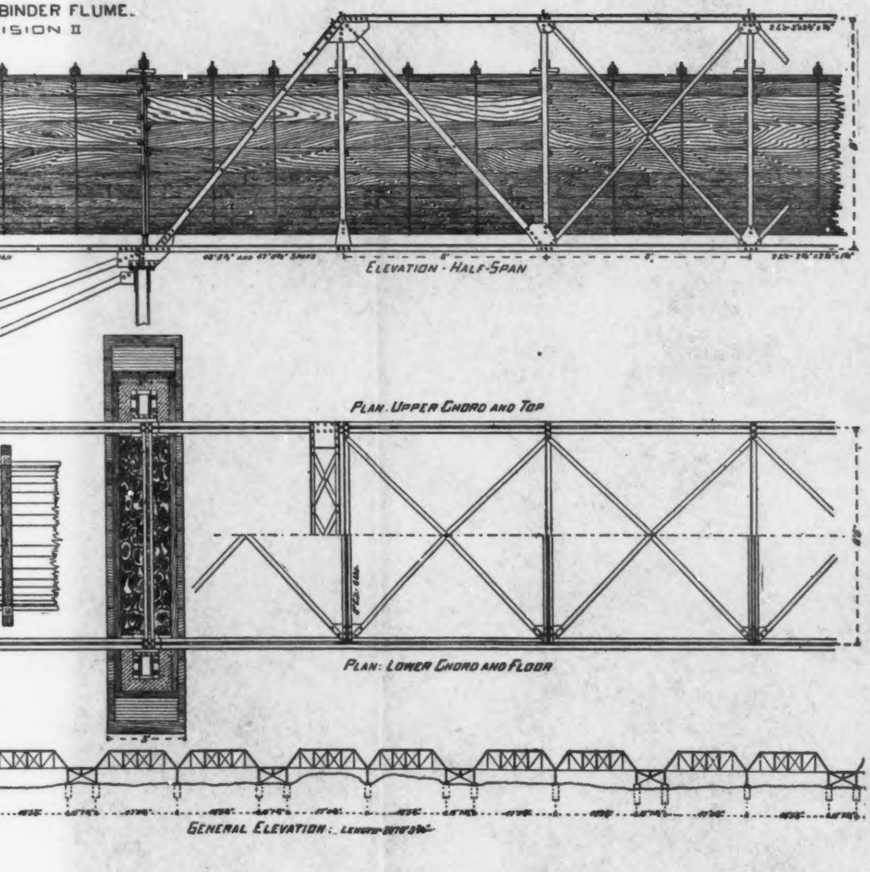


PLATE XXIII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. XXXIII, No. 743.
HALL ON SANTA ANA CANAL.

K STEEL BRIDGE
PPORTING
BINDER FLUME.
ISION II



The foundations of these piers rest on two layers of 3-in. redwood plank, and go down to where it will probably remain unrotted for many years. A better class of foundation pier was certainly to be desired under this structure, but neither time nor means at command would allow of improvement over that which was put in.

Mill Creek is a torrent like Santa Ana River, having a winding channel in this wide wash of boulders, cobbles and gravel. At times of great flood it changes its channel, but its washings at such times are not over 6 ft. in depth through the detritus; and the belief is that the piers put in at least will never be undermined. Should the rolling of boulders batter any one of them badly, this simply involves recasing before another flood comes, as floods are here of very short duration. These foundation piers are 13 ft. 6 ins. x 2 ft. on top, and the subplatforms on which they rest are 16 ft. x 3 ft. for a pier 8 ft. 6 ins. high. The concrete occupies compartments of the casing 2 ft. square on top and larger below, as shown in the section.

As to the construction of the bridge ; the plans illustrate its general features sufficiently, and it would be foreign to the subject proper of this paper to enter into details of a bridge design and building account. The width of bridge between center lines of chords is 8 ft. $5\frac{1}{8}$ ins. The 48-ft. Pratt trusses have six panels, each 8 x 9 ft. Both the floor and top chord system are lattice braced, and portal sway bracing is also introduced.

The floor beams composed of light channel bars in pairs, placed at 8-ft. spaces, and falling at the panel posts of the 48-ft. spans, and at the ends and centers of the 16-ft. spans, also serve as sills for the flume frames. The flange of the T-rib flume frame sets between the two channels ; a cast-iron chock fits up each side of this center bearing, and the L iron bracket braces of the flume bolt on to the iron floor beams just as elsewhere, to the wooden sills of the flume in general, only that for the frames to go on the bridge the bracket braces had to be made longer because the curved center part of the rib was not let down into the sills.

The highest steel pier is 14 ft. on top of a foundation pier 4 ft. above the ground line, and, generally, the structure is 8 to 10 ft. above the boulders of the wash.

This bridge was built under contract by the Massillon Bridge Company, of Massillon, O., according to the plans prepared by Mr. A. Bar-

mann, C. E., under the writer's supervision, but all the erection work was done by day labor.

Its total billed weight, including steel of piers, was 135 740 lbs., as against a plan estimate of 134 254 lbs. The weight used in estimating on cost was 140 000 lbs. Each 48 x 9-ft. truss weighed about 4 840 lbs., and was shipped as a whole on two cars, no serious damage being done the members in transit.

Erection was accomplished by means of derricks and without false work, for there was practically no water in the stream at the time the work was in progress, and a wagon road was constructed the length of the work. The connections were all hot-riveted in erection, and the whole given a coat of red lead in oil after completion, making the second coat from the shop.

Cost.—This steel substructure, with the flume it carries, cost as follows;

For the bridge, 1 072 *ft. in length:*		
Foundations—Excavation	$650 10	
Pier casings and platforms	1 024 70	
Bearing pillars, concrete	503 00	
Ballast, cobbles and gravel	49 50	
Back fill and paving around piers	53 75	
Abutment bearings, masonry	56 75	
Total		$2 337 80
Spans and piers—steel, f. o. b. Mentone	$6 380 25	
Unloading and hauling	238 35	
Erecting and riveting	643 20	
Painting, labor and materials	99 95	
Total		7 361 75
Total		$9 699 55
For the flume, 1 215 *ft. in length:*		
Grading, in approach		$17 25
Foundations—Excavation	$10 20	
Concrete footings	21 70	
Total		31 90
Flume—materials	$2 175 27	
Labor	389 90	
Delivery and subdelivery	131 25	
Total		2 696 42
Total		$2 745 57
Grand total		$12,445 12

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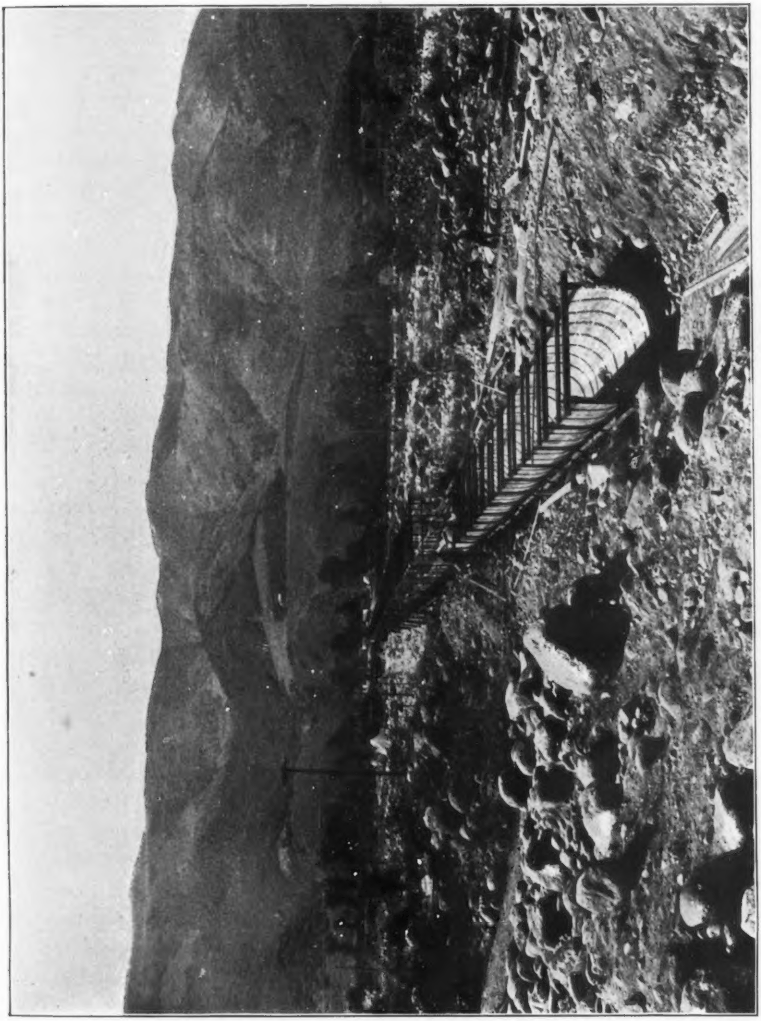

The bridge cost at the rate of \$9 05 per foot, of which \$2 18 was for the foundations and subpiers, and \$5 95 for the steel piers and spans, and 91 cents for delivery, erection and finish of the iron and steel work.

The flume alone cost \$2 22 per running foot ; that portion on the ground grade cost \$2 57, including grading and foundations ; the bridge and flume, as an aqueduct, cost \$11 27 per running foot.

For changes in iron work and experimenting on this piece of flume there were expended, in addition to the above, \$143 45 ; thus bringing the total to \$12 588 57. But this additional cost is properly a general expense item, chargeable to the entire flume construction, rather than to this one piece alone.

Foundations and Substructures.

All foundation blocks, except those of the flume sills where resting on earth (but a small part of the whole), are made of concrete or of rubble masonry in strong lime and cement mortar. All bearing posts and trestle and timber pier sills rest on such blocks of masonry built on either rock or very firm and hard clay foundations. In some cases these masonry piers had to be carried as much as 8 to 9 ft. below the ground surface. Generally, however, fairly good foundations were had in division I by 2 to 3 ft. of excavation, except at the cañon pipe crossings, where the deepest pits were found necessary ; while at the ravine flume crossings in division II the excavations were generally 4 to 5 ft. in depth.

In every case at the bottom of cañons and ravines the supports of the spans over the waterways were bedded on full masonry subpiers 1 ft. longer and 10 ins. wider than the sills placed upon them. Thus, according to the size and arrangement of posts in the trestle or pier superposed, these subpiers were 2 ft. 2 ins. to 2 ft. 6 ins. wide and 12 to 18 ft. long on top, and with batter slopes, as next described for the separate footing blocks.

Trestle and timber pier bents elsewhere placed were supported by three masonry footing piers each. These little footings were 18 ins. square on top and sloped to 4 ft. square at 5 ft. below their tops, and thence down the faces were vertical. All sills and footing blocks were laid in mortar on their masonry beddings. The tops of all masonry piers and footings were built to at least 18 ins. above ground line, so as to keep the sills free from earth influence.

According to circumstances, the supporting posts used are 4 x 6 ins., 6 x 6 ins. and 8 x 8 ins. The 4 x 6 ins. only for short flume-sill supports, the 8 x 8 ins. in a few of the highest trestles only. The sills and caps of trestles and pier posts are all 6 x 6 ins. or 6 x 8 ins.; the braces all 4 x 6 ins., 3 x 6 ins. or 2 x 6 ins., according to application, generally the larger sizes; the stringers, all 4 x 16 ins., and bolted up in pairs on 1.5 x 3-in. cast-iron separators, are applied in 32-ft. lengths, where admissible, as girders with 16-ft. spans.

The trussed girders are all in 32-ft. spans, and consist in each case of the pair of 4 x 16-in. stringers, trussed with a $1\frac{3}{8}$-in. hog-chain rod, upset at all ends to $1\frac{3}{4}$ ins. before threading, and bearing on plates $\frac{1}{2}$ x $3\frac{1}{2}$ x $9\frac{1}{2}$ ins. Each such rod is divided in the center and provided with a turn-buckle. The trusses are made with two 6 x 6-in. x 4 ft. 9-in. hog posts, provided, of course, with suitable foot and cap castings. All such trusses rest on corbels about 12 x 12 ins. x 2 ft. 6 ins. across the caps.

All truss end supports are made on double postings, bolted up together on cast-iron separators. The general arrangement of trusses and string girders is in alternation, the string girders being within the braced timber pier and the trussed girder between two such piers. All foot and top bearings of posts in trestles were dapped into place and drift-bolted; all sway and string braces thicker than 2 ins. were dapped on or cut around the member closed upon, and all were thoroughly well spiked thereto with wire nails about as long as the wood would admit of. This form of nailing braces for this purpose is preferred to bolting.

All stringers are dapped on and drift-bolted to the corbels, and all corbels are dapped on and drift-bolted to the caps. Nearly all the trestle framing and all the stringer and girder cutting was done in the company's yard, so that only erecting work proper was done in the field.

The flume-supporting substructures are all complete for the full finished work to carry 240 second-feet of water. On the trestle bents and timber piers the flume sills or bolsters are held by three string girders or trussed girders, according to span—whether 16 or 32 ft., as above described—one on each side and one in the center. All flume sills are iron strapped to the outside stringers on which they rest, except in protected places and on curves in the cañon, where they are toe-spiked.

The pipe-supporting substructures are all up, but not quite complete, to carry the second pipe. The weight of the two pipes of water will be greater than that of the full flume, and greater undistributed strains are to be anticipated in the structures under them. The immediate pipe-sill support now consists of two string or trussed girders, according to the span. The one at center of trestle, being intended to serve in part as support to the other pipe also when put on, will be doubled when this is done, and the third one will be placed on the opposite side for the outer support of the additional pipe sills; and, at the same time, additional posting will be introduced into the centers of the bents.

The total lengths of substructures of this class is 3 345.5 ft.

Cost.—In division I there are 36 flume-supporting substructures whose aggregate length for full flume width is 1 024 ft. These took about 46 000 ft., B. M., of lumber, 15 800 lbs. of wrought iron and 4 850 lbs. of cast iron, and cost, erected, \$2 857.73; of which \$1 859 was for materials, \$285 for delivery and subdelivery from the company yards, and \$713.73 for labor of framing and erection.

The substructures carrying portions of the Warm Springs, Deep Cañon and Morton Cañon pressure pipes aggregated 880.8 ft. in length, horizontal measurement. There were used in them about 67 000 ft., B. M., of lumber, 7 650 lbs. of wrought iron, and 4 370 lbs. cast iron. It cost \$3 228 20 to purchase, deliver and put this material into the work, or \$3 78 per running foot. The cost of grading, masonry piers and footings and of the separate substructures is given elsewhere.

In division II, besides the steel bridge there are six substructures, aggregating 1 440 ft. in length. These took about 57 500 ft., B. M., of lumber, 7 640 lbs. of wrought and 3 000 lbs. of cast iron. The cost was \$2 537 73, of which \$1 541 84 was for materials; \$258 for delivery and subdelivery and hauling in the field, and \$737 89 for labor of framing and erection.

The Waterway.

There are six classes of conduit thus far designed and built for the Santa Ana Canal, namely, open tunnel, walled canal, lined canal, flume, pressure pipe and piped tunnel. The first three have a smooth cement plaster finish, the last three a close-jointed, planed wood surface.

The waterway through all the open tunnels is designed to one

standard section. The walled canal presents very nearly, but not quite, the same channel, while that of the lined canal is quite different. The pressure pipe and piped tunnel have similarly formed cross-sections, but their sizes differ greatly. The flumes all have the same width and shape of bottom, but those in division II are planned a foot deeper than those in division I. Hence, there are seven standard sections of the waterway provided for in this aqueduct, and (other functions into account as well) seven different mean current velocities will be generated when it is carrying the same volume of water by them all.

Besides minor variations from the expected current rates, which will be caused by curvature in alignment, by the changing from one gradient and form of section to another, and by the influence of conditions immediately preceding and succeeding those of each distinct part of the aqueduct, there will also be variations of flow caused by exceptional treatment of the conduit itself, as, for instance, its division into two at the pressure-pipe crossings.

Within the 29 095 ft. in length now built, there are planned 37 different pieces of aqueduct, besides three sand-box and seven wasteway structures, six special pipe-joining bays, seven special flume-entrance pieces and seven canal-entrance sections. In other words, the water prism is required to change its sectional form and mean rate of movement 36 times after entering the headgate, and 13 special constructions are provided to help it so to do with the least (attainable) loss of head and disturbance of conditions of flow, and 23 other minor adjustments are made to the same end.

Three special constructions are planned as part of the conduit, but, at the same time, for the express purpose of causing the water to slacken its speed and drop its sands and sediments. And seven other arrangements are introduced for occasionally turning the whole or part of it out; but, always with the desire to disturb its normal flow, through or past them, as little as possible when they are not in use.

As elsewhere herein explained, not all of the sand-boxes and wasteways have as yet been built, and some of them have not been commenced. In other respects, though, the general facts shaping the hydraulic problems of the work are as above stated. As the basis of design the study was first made for the full capacity of 240 second-feet, and then for the half quantity, 120 second-feet, of the

proposed temporary finish; and, finally, tests were made by calculation, to see what the conditions would be in the conduit suited to those duties when only 20 second-feet, the supposed minimum working flow, would be running. On the basis of such tests the sizes, forms and gradients of conduits of the different kinds suitable to be adopted were determined. The mean velocities were calculated by Kutter's formula, using Flynn's combined elements and coefficients, and with $n = .010$ for planed lumber and .012 for smooth plaster finish. The calculated results are shown in the following table:

CALCULATED CAPACITIES OF THE SEVERAL PARTS OF THE WATERWAY WHEN FULLY FINISHED.

	Depth of Flow. Feet.	Width of Surface. Feet.	Area of Prism. Square feet.	Sine of Slope.	Mean Velocity per Second. Feet.	Discharge.	
						Second-feet.	Miners' Inches.
Tunnel No. 1	5.3	5.75	29.50	0.00200	8.85	261.0	13 050
Walled canal	5.3	6.00	30.00	0.00175	8.36	250.0	12 500
Flumes Nos. 1 to 9	5.0	5.50	25.08	0·00175	9.71	243.6	12 180
Tunnels Nos. 2, 3, 4, 6 and 7	5.3	5.75	29.50	0.00175	8.29	246.0	12 300
Pressure pipe No. 1	4.33	4.33	14.75	0.00270	8.55	126.0	6 300
Pressure pipes Nos. 2 and 3	4.33	4.33	14.75	0.00370	10.00	147.5	7 375
Tunnels Nos. 5 and 8	5.3	5.75	29.50	0.00200	8.85	261.0	13 050
Tunnel No. 9	6.0	6.00	28.27	0.00244	10.01	282.7	14 135
Canals Nos. 1 to 7	6.5	11.50	51.90	0.00075	4.94	256.4	12 840
Flumes Nos. 10 to 16	6.0	5.50	30.58	0.00175			

The pipe capacities are given for one pipe only. The depths of water shown for the pipes and the piped tunnel are, of course, the measure of their diameters. The depths for the remaining parts of the conduit are such as would bring the water up to even planes throughout; that is, the differences in depth represent the differences in relative elevation of the bottom planes of the several parts of the aqueduct. Thus, for any one of the open conduits, an apparent excess of capacity over one of another kind merely indicates that, to equalize them, its flow would not have to be as deep as indicated.

Keeping these points in view, to carry the half quantity, 120 second-feet, for which the work is now finished, the depths of flow in the principal parts of the aqueduct would be, theoretically, about as follows: For the flumes in division I, 3 ft.; for the short tunnels, 3.2 ft.; for the long tunnels, 3.1 ft.; for the flumes in division II, 3 ft.; for the lined canal reaches, 4.4 ft.

Again, to carry 20 second-feet, the depths of flow would be about as follows: For the flumes in division I, 1.10 ft.; for the short tunnels, 1.08 ft.; for the long tunnels, 1 ft.; for the flumes in division II, 1.10 ft.; for the canal reaches, 1.7 ft.

These figures, according to our formula and chosen coefficients for roughness, indicate the relative capacities of the several kinds of waterway as built in the work. Taken into consideration with the following remarks, whose application must modify one and all to some extent and at some points, they indicate about the manner in which the parts of the aqueduct are expected to work, without attempting to lay down a water line throughout for any one volume of flow.

Keeping in mind that the desired full capacity is 240 second-feet, the following points may be noted: Tunnel No. 1 was given excess in grade slope and apparent capacity to assist entry at its head. The piece of walled canal was given increase of width and apparent capacity, because, with the labor used, its surfaces were likely to be less true than those of the tunnel and flume, and, indeed, notwithstanding careful supervision, this is the case; there are such irregularities in its walls as will go far towards offsetting the advantage given it by the greater width than the tunnel has; and the rational thought seems to be that the water plane would so adjust itself as to produce about a uniform slope and central velocity from immediately below the intake to the head of the first flume.

Under these conditions the mean velocity would be about 8.7 ft. per second as the water approached the flume. But at that point a head would have to accumulate to produce the additional 1 ft. per second in velocity requisite in the flume section, and, at the same time, raise the center of gravity of the water column about .15 ft. on entering the flume. This piling up of water would have its reflex action on the slope in the conduit above it, probably nearly back to the tunnel. The exact conditions which will exist seem to be indeterminable. This, substantially, would be the case at the point of entry to each reach of the flume from each succeeding tunnel in division I. The adjustments are based on judgment as to such details. The short tunnels, Nos. 2, 3, 4, 6 and 7, are given slightly excessive grade slopes and apparent surplus of capacity merely to further remove the possibility of choking the waterway at these points, which would cause overflow from the flumes above them. That the resultant additional fall due to each

of these breaks in slope, considering the shortness of each tunnel, is insignificant, and that the change in grade slope would not be apparent on the water surface, goes without saying. The break in the bottom plane, due to excess in depth of tunnel over that of flume section, would have a greater influence when there is little water running; and when there is much, both these effects, it was thought, would be effaced, for here again the accumulation of head at the flume's entrance will be the controlling influence on the gradations of surface for some distance each way. The apparent excess of capacity given these short tunnels is to be regarded merely as a slight leaning of the judgment towards what is manifestly the safe side.

A more decided leaning in that way is to be noticed in the still greater grade slope and apparent capacity of the long tunnels. A tendency to choke the water column at the short tunnels might be overcome by an immaterial accumulation of head above them. A proportionate tendency the same way in the long tunnels would be a more serious matter. Our hydraulic formula may be in error, or the coefficients of roughness not well chosen. Hence, the still greater slopes given tunnels Nos. 5 and 8.

Practically the same idea governed in adjusting the hydraulic grade slopes of the pressure pipes; only the problem, for manifest reasons, was considered still more obscure, and hence greater margins were allowed. The short pipe was given slope enough to carry, according to our formula, 6 second-feet more than half the full aqueduct's volume, and the longer pipes were given capacities of about 27 second-feet in excess of the same half flow. The short one might be forced by an immaterially slight accumulation of head, and it opens out into a flume which will surely carry as much as the flume above it. One of the long pressure pipes delivers into the longest tunnel and the other into the piped tunnel, through the penstock, both representing conditions comparatively obscure as to reflex influence on capacity above. Hence, the greater hydraulic grade slopes allowed on the longer pipes than on the shorter. It may be remarked here that these rates of slope are allowed on the basis of the actual lengths of the pipes, and not merely on their lengths as structures, horizontally, in the line. But no special allowance was made for resistance due to curvature. This, under the facts already stated, was thought unnecessary. A sufficient hydraulic gradient was allowed for over tunnel No.

9 to give it apparent capacity equal to the pair of pipes which will ultimately come into it. And, although there is a difference shown by the calculated figures, the result, it was thought, would be that, barring the disturbing influences of the penstock junction, the hydraulic gradient would adjust itself nearly as one plane over these pipes and the piped tunnel in controlling flow through them.

Finally, the alternating canal and flume reaches in division II. As will be noted, the flumes are generally short, and some of the intervening canals are quite short also. Notwithstanding the provision made to facilitate entry from canal to flume sections, and notwithstanding the fact that the flumes are made 1 ft. deeper and with over 20% more area available than sufficient, according to our formula, to carry the requisite amount of water on the gradients allowed, above every flume entrance there would be a head accumulated sufficient to produce the increased velocity necessary to put the water through the smaller flume (than preceding canal) section. What would be the influence of this? Manifestly, such as to change largely the conditions in the canal reach for a considerable distance above. Further, the writer's observation of such matters has indicated that in the cases of the shorter reaches of flume the water plane would not adjust itself to the flume bed at all, but be so influenced by that in the reach of canal each way as to assume some slope (slightly concave and not a true sloping plane) between the level taken by the water surface just within the head of the flume and that in the canal reach below; and this again would be complicated by the counterhead produced in the canal section immediately below the end of the flume in consuming surplus velocity of water delivered from it. In the longer reaches of flume, and especially in that 1 215 ft. in length at the Mill Creek crossing, the water, it would seem, will become adjusted to the flume gradient; but it cannot be so adjusted for nearly the full length of the flume, because the flume section is 1 ft. deeper—its bottom is 1 ft. lower—than sufficient to afford the requisite waterway on the grade set for it, and hence there would be this foot of back water at the lower end of the flume, as modified by the counterhead necessarily created in consuming surplus velocity received from the flume at the beginning of the canal section.

These remarks are not intended as a technical discussion of the problems involved, but merely to point to them and to indicate in a general way the line of thought traversed in designing the aqueduct.

Cost of Work.

The construction herein described is certainly not one in which, even under the most favorable conditions as to labor and material, it might be expected to do work at rates that could appear cheap, compared to results of well-situated examples conveniently disposed for handling. The roughness and inaccessibility of the immediate sites of most of the structures, and the scattered, small and odd-shaped parcels in which, as a general thing, work of any distinct character is found—all conditions tending to increase cost—should be apparent from the foregoing descriptions. The following analysis of costs still further exemplifies these facts:

Rock and Earthwork.—The excavation and movement of earth and rock had a wide range of cost, as the conditions varied. The flume bench grading, of which there was in all about 42 270 cu. yds., cost between 15 cents and $1 41 per cubic yard. About 12 700 cu. yds. of earth cost 15.2, 18.4 and 16.7 cents respectively in the three sections estimated. Much of this was sandy earth, which shoveled freely; most was moved but one shovel's cast, some was cast twice, a small portion wheeled in barrows, a smaller portion scraped. About 27 450 cu. yds. of rock cost 42, 49.5 and 51.5 cents per cubic yard respectively in the three sections. Much of this was soft rock, taken out with pick and cast over the grade, at costs between 30 and 40 cents per cubic yard; a small portion was hard rock, which cost 90 cents to $1 10 per cubic yard, using powder, gads and crows. There was also 2 122 cu. yds. of tunnel approach work, mostly rock, done by contract at $1 41, transferred into this flume bench account as elsewhere explained. This latter rate was 40% too high for the average of the work done under it. The deterioration of labor efficiency is plainly apparent in the above figures. The work in section III was done after the labor trouble commenced. By comparison of materials, it should have cost at least 10% less per cubic yard than that in section I. It did cost 15 to 20% more. The grading for the pressure pipes cost at the rates of 22 to 26 cents for earth, and 52.9, 49 and 59.9 for the average of each of the three jobs respectively; there being in all 4 660 cu. yds. of material moved, full three-fourths of which was on very steep ground, where it was inconvenient and often difficult to work. Labor on these pipe grades was certainly 25% below the normal in efficiency.

The canal excavation cost, by contract, 24 cents per cubic yard.

The preliminary estimate was 25 cents. Notwithstanding the fact that some heavy cobbles, gravels and even boulders were encountered, and that some blasting had to be done, it was a paying contract. The material was loosened with heavy plows drawn by four and sometimes six heavy mules. The top was taken out sideways, with slip-scrapers, and the bottom lengthwise and up runways, with small wheel-scrapers. The top-soil movement under this contract was worth about 10 to 12 cents per cubic yard; the cobbles and boulders, about 20 to 24 cents; and a very small portion, about 36 cents. Following the rough excavation under this contract, the ditch was bottomed and dressed for lining on force account. As near as can be told, there having been no accurate measurement made of quantity, this work cost between 70 and 80 cents per cubic yard, 30 to 40% more than it would have cost had the labor conditions been normal and superintendence efficient.

The excavation of foundation pits and benches cost, according to location, material, bulk of job and time when done, between 40 cents and $3 per cubic yard. Small excavations in rock, at scattered points, as for flume footings where it was not desired or would not have paid to use powder, ran up the highest. Earth in quantity of course cost the least. The pits for trestle foundations for the pipe substructures, in earth, gravel, cobbles and soft rock cost 81.4, 97.5 and 85 cents per cubic yard for the three crossings. The pits and benches for flume substructure foundations in division I cost on the average $1 26 per cubic yard, the rock generally being hard and the points of work scattered. The pits for foundations of substructures in division II, where there was firm earth, clay and boulders and no rock in place, cost between 90 cents and $1 per cubic yard, and with a labor efficiency at least 25% below the normal. Foundation clearances and excavations for local structures in division I cost, for rock, $1 50 to $1 75 per cubic yard; for soft rock, $1 to $1 25; for earth and clay, 40 to 80 cents, according to circumstances. The labor deterioration on these works was less uniform, but in some later cases reached the extreme of 40 per cent. On the average it was about 20 per cent.

Rubble and Boulder Masonry.—The masonry work is found in 21 structures and 46 substructures. For the latter there were built over 320 footing blocks and pier bases. Of these, about 120 in the cañon division averaged about 1.5 cu. yds. in volume each, and 200 in divi-

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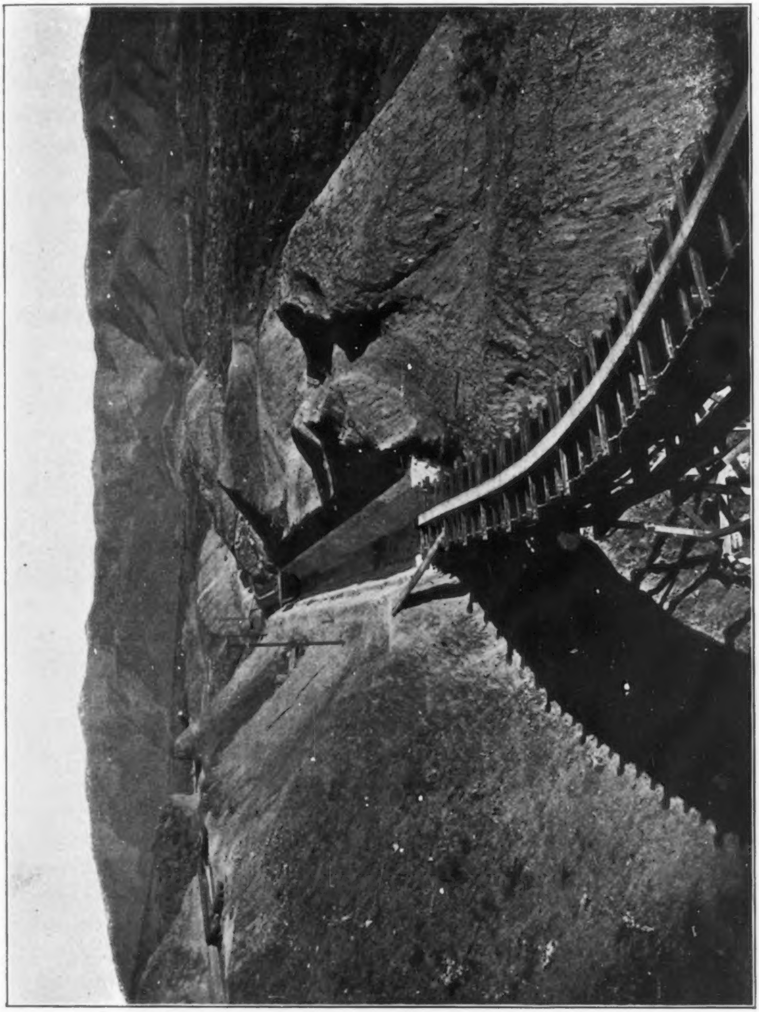

sion II only about .7 cu. yd. Many of these little blocks are at spots on steep mountain sides, difficult of access and inconvenient to work at, and all are strung out over long lines of work, necessitating much movement of force and complication in delivery of materials. Of the local masonry structures, nine had an average of about 3.7 cu. yds. each; five, about 17.4; four, about 60.3, and the three largest, 130 to 160 cu. yds. apiece. These also were scattered and at inconvenient places—more than half—high up on the cañon side in division I.

Still, again, the canal lining, which is not included with the above, is, of course, disposed in thin walls and pavings, so that the labor of delivery and placing materials into it could not be brought to as low a figure as though it were in more concentrated mass.

With respect to quality, the masonry may be ranked in three classes: first, that put in cement mortar to withstand, without backing, water pressure or earth thrust, or to bear heavy weight; second, that also in the form of upright walls, in a strong lime and cement mortar, but backed with earth or reinforced with concrete; and, third, that laid on slopes, as canal lining walls, with less mortar and with still less cement in it. The paving of canal bottoms is not ranked with masonry, but as dry rockwork, though it was afterwards covered in with cement mortar in the process of plastering, and the spaces between stones are, in a measure, thus filled with mortar.

Of first-class masonry there were about 955 cu. yds. put into the work, using 480 bbls. of cement and 48 bbls. of lime, at a total cost of $7 840 59, or an average of $8 21 per cubic yard. Of this, the largest block, sand-box No. 1, cost at the rate of about $7 76 per yard, and this was the cheapest work of the class done, except some small blocks at the lower end of the work, where there was little or no expense for delivery of stone. Materials for the sand-box were all obtained within 300 yds. of the work and without the expense of quarrying, and were delivered in wagons, but over very rough roads. The cement cost, delivered, about $3 60 per barrel. The masonry in the next largest structures, the five junction bays, ranged in cost from $8 41 for those at the Warm Springs' crossing, to $9 75 and $11 41 for bays Nos. 3 and 4, and $10 60 for bay No. 5. For No. 1, the material had to be gathered in the wash and hauled in wagons for 100 to 300 yds.; then taken up a tram or skidway in small cars, as elsewhere described, and then carted along the bench about 200 yds. For No. 2 delivery was made in wagons

300 to 500 yds., total, with a stiff uphill haul of about 200. Cement for these cost, delivered, about the same as for the sand-box. Rock for No. 3 was gotten off the mountain side above, but at much disadvantage, from large scattered boulders, rolled down to the flume grade, and along it carted to the work. Cement, sand and water had to be hauled from the river wash, a distance of nearly a mile, and elevated about 350 ft. over a steep road, in wagons, and then, in order to get through tunnels and over trestles, brought in small loads on a narrow-gauge truck with one horse for over 1 000 ft. along the bench.

Cement for this work cost about $4 10 per barrel, delivered. Materials for bay No. 4 were hauled in wagons about ½ to 1 mile from where gathered, up a steep cañon road and then carried up the cliff on the tram car about 100 ft. higher. Cement cost about $4 on the spot. Delivery was made to No. 5 in wagons with a haul of over 1 mile, and rising about 400 ft. mostly in two short steep pulls. Cement cost about $3 75. There were 273.2 cu. yds. of masonry put into these junction bay walls, at a total cost of $2 616 76; average, $9 51 per cubic yard. This class of masonry in tunnel, portal and wasteway structures, where the masses were smaller and the forms of laying more expensive, cost, where delivery was a small item at the headworks, $8 18 per cubic yard; on the lower benches, $10 32; on the higher and more inaccessible sites, $11 20 and $11 32, and at the most inaccessible point, tunnel No. 6 and wasteway No. 5, to which all materials had to be brought, as in the case of water, sand and cement for bay No. 3, the cost rose to $12 64 per cubic yard. In the little blocks for flume substructure footings on this mountain side in division I the masonry cost $11 18, $12 and $12 10 in the three sections accounted for separately; with the cement, subdelivered, at $3 75 to $4, and subdelivery of other materials varying as above described.

In the Warm Spring pipe substructure footings and pier bases, where rock was gathered in the wash close around, and there was no expense for delivery of water, this class of masonry cost $5 92 per cubic yard, with cement at $3 65, delivered. This same class of work at the Deep Cañon crossing, rock gathered in river wash, and all materials, except water, hauled about a mile up a steep cañon road, cost $10 05 per cubic yard, with cement costing $3 60 on the spot. And at Morton Cañon pipe crossing, with cement at the same figure and water equally convenient, but less haul for other materials, the cost was $9 40 per cubic

yard. In division II, where there was no expense for subdelivery, all materials being dumped conveniently from wagons, and with cement at a uniform cost of about $3 50 per barrel on the spot, this class of masonry cost between about $5 90, where there was no haul for rock and but little for sand and water, and $10 60 where all materials had to be gathered at disadvantage and hauled from the river wash over a steep road for about 1¼ miles. In this division the footing blocks of flume substructures cost about $7 per cubic yard, all materials hauled an average of 1¼ miles, but there was somewhat less cement used in these than in similar masses in division I.

Second-class masonry in division I, where delivery was convenient, haul not to exceed 200 yds., no charge for subdelivery, cement at $3 60 and lime at $1 90 on the spot, cost about $4 52 per yard in laying up 158 yds. in walls 1.5 to 2.5 ft. thick and 6.5 ft. high, against earth backings. There were in all 181 cu. yds. of this class of masonry put into the work—using 25 bbls. of cement and 75 bbls. of lime—at a total cost of $838 87, or $4 65 per cubic yard.

The third-class masonry in canal linings of division II was about 4 400 cu. yds. in volume, and in it were used about 553 bbls. of cement at about $3 50, and 811 bbls. of lime at about $1 80 per barrel on the spot. Its total cost was $12 987, an average of $2 95 per cubic yard, but the rate varied between $1 98 per cubic yard—where cement cost $3 45, lime $1 75, and all materials, except sand, were immediately at hand, without haul—and about $4 where the haul for all material was over 1 mile, and the cost of delivering cement and lime was 8 cents greater per barrel.

Bottom paving, dry, chinked and sanded, cost about 60 cents per cubic yard, where the work consisted in simply putting back into paving the cobbles taken out in excavation, and from that up to $2 40 per cubic yard, where the haul was greatest and delivery least convenient. The total volume of this work in the canal was about 1 092 cu. yds.; the total cost, $1 352 85; average, $1 24 per cubic yard, or 2.3 cents per square foot, averaged at 6 ins. thick.

Finally, about 52 cu. yds. of dry rock walls, built as backing and including the temporary headwork's wall, cost $133 83. Some of this was at as low a cost as about 55 cents per cubic yard, where it was a mere matter of piling rocks gathered immediately at hand. Some ran up to several dollars per cubic yard, according to cost of delivery.

Several small jobs of rock fill, aggregating 283 cu. yds. in volume, cost $216 53, with haul all within 200 yds. distance, and materials gathered off the wash.

Concrete.—In the proportions elsewhere given (and as to which there were some unrecorded variations in the practice) concrete entered into 27 distinct structures, besides 24 mere connections, and the flume and pipe-sill fittings. Its cost had a wide range, according to circumstances. That, where all materials were most convenient, with very small charge for hauling them and cement at $3 60 per barrel on the spot—as at the headworks—cost about 29.5 cents per cubic foot; that at the lower end of the works, with materials somewhat less conveniently situated and put into the bridge piers, cost 31 cents ; that in the sand-box, with somewhat more cost for hauling of aggregates, cost 33 cents ; and that in the junction bays, according to cost of hauling and degree of convenience at the work, cost 35.6, 49.3, 41 and 38 cents per cubic foot. Where put into tunnels, behind mould boards which had to be placed and removed at a charge to the result, the concrete cost 32.7 cents at tunnel No. 1, with least cost at tunnel mouth, and 48.5 cents at tunnel No. 7, with maximum cost at tunnel mouth, both tunnels being short and lined for full height of waterway. While for tunnel No. 8—the long tunnel, lined only at bottom and sides 1 ft. high—the cost was at the rate of 44 cents per cubic foot. That put into tunnel No. 9, where the cost of lagging was not a charge against the concrete, with cost at portal a little less than at tunnel No. 8, cost 42.2 cents ; but the work was much impeded and the labor made excessive by the extreme of conditions elsewhere referred to, and the lining work was all done from one end. The flume footing blocks cost at the rates 43.5, 43.4 and 49.1 cents per cubic foot, in the three sections respectively. The pipe footings cost 34, 40 and 39.7 cents per cubic foot. The difference from flume footings is due to the pipe footings being in much larger masses and more conveniently placed for work and delivery of materials. In all there were 18 666 cu. ft. of concrete put into the work, using 748 bbls. cement, at a cost of $7 653 35, or 41 cents per cubic foot.

Plaster Finish.—The plaster-finish work also had a wide range of cost, depending not only on those circumstances which so much affected the cost of masonry and concrete, but on the thickness to which the plaster was spread and the exposure and weather and consequent

measure of necessity for keeping it wet after spreading. The cost ranged from 3.8 cents per square foot—where delivery was most convenient and with cement at $3 50 per barrel—and 6.4 cents under conditions most unfavorable. At the upper end of the work, with cement at $3 60 per barrel and hauling about at the minimum, for the larger pieces of work in the open, the cost ranged between 4 and 4.5 cents per square foot. In tunnel No. 1, same locality, it cost nearly 5 cents. Generally along the high bench, in small quantities, the cost ranged between 5 and 6.4 cents. For the largest surfaces of the junction bays in the same locality, the rates were 4.4 to 6.2 cents. In tunnels on the bench it cost about 6 cents where delivery was highest at tunnel mouth and somewhat less than 5 cents in the long tunnel, No. 8, where cost at tunnel mouth was less. The larger plastering job of the canal, in division II, where more plastering was used in covering the invert, but where delivery was cheapest, cost an average rate of 3.85 cents per square foot covered—invert and walls taken together.

Summary—Masonry, Concrete, Plaster, etc.—Summarizing the work in which lime and cement were used, the following result is obtained :

Classification.	Volumes of work. Cubic yards.	Quantities, Materials.		Ratios—Work to Materials in cubic yards per barrel.		
		Cement. Barrels.	Lime. Barrels.	Of cement.	Of lime.	Of cement and lime.
Masonry, 1st class	955.0	480	48	1.990	19.90	1.81
" 2d "	181.0	25	75	7.240	2.41	1.81
" 3d "	4 400.0	553	811	7.940	5.42	3.22
Brickwork, 1st class	14.0	5	....	3.000	....	3.00
Concrete	692.0	748	....	0.926	....	0.926
Plaster	183.5	413	20	0.444	9.00	0.424
Totals	....	2 224	954			

This account is not based on accurate data as to every item. It would have been a useless labor to closely measure the volume of every little block of work which goes to make up these totals, and a hopeless task to trace the distribution of materials accurately and in detail into them. The principal works were dimensioned in the plans

and measured as executed. The smaller works, for which no individual plans were made, were carefully inspected, roughly measured and estimated from such data, and checked by reinspection. Account was kept of materials put into each structure, and instructions were given as to proportioning them into different classes of work. Separate accounts were kept of actual use of materials for each class of work in some of the larger jobs. From such data the account has been made. The fact that the volumes of second and of first-class masonry, per barrel of cement and lime together, are shown to have been the same, is purely accidental, or rather the result of the practice based on the instructions as to proportioning. The proportioning was not always the same in either class—in some works more, in some less, than shown as the averages above. The apparently small amount of lime and cement, the small proportion of mortar, used in the third-class masonry, the canal walls, simply illustrates the fact that these walls are only one tier of stones thick. There was no attempt made to back the lining with mortar; only the bedding joints were filled with it, and where filling was needed between the stones of the wall and the bank slope, earth was rammed in.

In considering these figures it is to be remembered that there was no expense for quarrying. The rock was gathered in the river and creek washes, or on the mountain or hillsides, and piled conveniently for loading. The washes afford an almost limitless supply of suitable clean granite boulders only partially worn and rounded. For some works rock was taken from the flume grade spoil banks, while others of these banks supplied most of the concrete material already well broken. Sometimes large boulders on the mountain side were shot to pieces for the first-class masonry rock, but a very small portion of the whole was obtained in this way, however. The canal lining and paving rock for the first 1 000 to 1 300 ft. of work was gathered from the excavation spoil banks or on the hillsides within 1 000 ft. of where used. That for the last or lower 1 000 ft. was obtained almost entirely in the excavation. For the balance of the lining work the haul on this material was from $\frac{3}{4}$ to $1\frac{1}{4}$ miles.

Sand and water cost about as much, on the spot of use, as rock did per volume-unit used at many points in division I and at some points in division II. Most of the third-class masonry—canal lining walls—and some of the second-class masonry and part of the first class, was put in

with common labor only, men generally at $2 per day, some at higher wages—average about $2.25. Most of the higher class work was put in by masons at $3 to $3 50 per day. The cement used was Gillingham's, which throughout was of uniformly good quality. The lime was a Southern California article, proved by use in other works to have decidedly good hydraulic qualities. Except in the mortar for second and third-class masonry, it was generally used only to make lime water to mix the cement mortar with.

Tunnels.—The actual force work cost of excavation of tunnel No. 9, averaged over its whole length, was about $3 10 per cubic yard. This was through hard, cemented gravel, cobbles and boulders—powder in moderation being required for most of the length and necessarily carefully used. There was some free pick ground in this bore, but not a great deal. This cost was fully 10% more than it would have been under normal labor conditions and efficient superintendence, though the work was finished before the trouble was at its worst. In the other tunnels, at contract prices, the rates varied between $5 25 and $6 10 per cubic yard removed. Actually (according to such accounts as could well be kept on the contract work), it varied between $3 and $6 per cubic yard, the quality of material (all rock, be it remembered), and length of tunnel and expense of ventilation being the chief limiting influences. Under normal labor conditions and with efficient superintendence these contract tunnels could have been driven, on force account, at about 25% less on the average than the contract prices. As it was, although the contractors suffered from the demoralization of labor, they were not nearly so much affected by it as was the company directly; so that, had the rock tunnel work been done on force account, it would probably have cost fully as much as the contract prices, if not more; though, notwithstanding the labor trouble, the contractors made money.

Flumes.—The cost of delivery of lumber for flumes ranged between $2 40 and $3 per M, and averaged somewhat over $2 50. Subdelivery ranged between $1 50 and $5, and averaged about $3 on that actually handled. The higher cost, of course, was for getting the material up the worst cliffs and along the most inaccessible benches. The yard and shop work, consisting of making sills, yokes, reducing sections, etc., and dipping in coal tar, charged only to material thus handled, ranged between $2 50 and $15 per M according to what was done with

it, the average being about $10. The cost of erection charged against lumber amounted to about $5 75 per M averaged over the whole. All labor, inclusive of calking and tarring, charged against preparing and putting lumber into the work, came to somewhat less than $9 per M put in; and this, with the delivery and subdelivery averaged over the whole, made the total rate about $14 per M. The mean cost of all lumber used was about $28 60, and thus we have a total mean cost of $42 60 in the work. Most all of the flume iron cost 5.25 cents at the company's yards. Some cast-iron was had at 3.25 cents. The average was about 5.2 cents per pound. The cost of delivery, subdelivery and putting nearly 150 000 lbs. into the work was about $2 000.

It must be remembered that the building of this flume was an experiment. The work was a quarter over before what appeared to be the best method of handling it was settled upon. The erection was nearly half over before there were any really well-trained crews or gangs of men at work on it. Not any one was skilled in it to start in with. There was less effect of the prevalent labor trouble apparent in this flume-building force than in any other, and it was under good superintendence; but even here it is entirely safe to count on a loss of 12% of labor efficiency, due to causes heretofore explained. It is thought that these flume figures will be specially significant to engineers who have had to do with irrigation works and have had experience with ordinary flumes.

Substructures.—The flume wooden substructures cost, for labor of yard work and erection, about $13 per M in division II, $15 50 in division I, and this cost for pipe substructures was about $18 50 per 1 000 ft. B. M. put into them—costs believed to be moderate under the circumstances; but it is thought that under normal conditions of labor this work would have cost 10 to 15% less, even though it was well superintended. This class of lumber cost $19 12½ per M at the company's yards.

The steel bridge cost for erection and riveting—labor, coal, etc.—0.46 cent per pound, or for the steel structure in place, 5.35 cents per pound, a price which will seem to engineers on the Atlantic seaboard enormous for such a structure. The freight from Massillon, O., to the company's yards at Mentone was at the rate of 1.35 cents per pound. And this was at a time of keen competition between the rival trans-

continental roads. The contract price at Massillon, O., was 3.35 cents per pound, f. o. b. Delivery from depot to works and sundries cost 0.19 cent per pound.

Materials.—The appended schedule shows the quantities and range of prices of the several kinds of materials used in the work. It would be tedious to consider them in detail. The writer is satisfied, as a result of careful inquiry on the subject and from his own observation and knowledge, that had the company been prepared to pay promptly, and with this fact substantiated beforehand, it could readily have purchased most of these materials at from 10 to 15% less than it did take them at, and for some it paid as much as 20 to 25% too much. There is no reflection cast by this, except on the bad policy of attempting construction without money absolutely assured to pay for it monthly.

Labor.—The wages paid, as shown by the annexed schedule, were very high for common labor. There was excuse for paying some laborers higher than ordinary, seeing that they were men of some experience in rock and canal-lining work, and on such duty were clearly worth more than the ordinary laborer, or than they themselves were at ordinary labor. But the higher wage rates were sustained throughout for these men on all classes of work. Men who commenced as drillers in rockwork, and skilled men as such, were paid $2 75 per day to the last, long after rockwork was over; and for the most part of the time they were doing for the company work of kinds, for which contractors paid only $1 75 per day. The reason was that the company was in their debt and could not discharge them or cut them down without precipitating a riot. A very significant fact was that they were men who had for years been in the personal employ of the superintendent during each recurring contract season, and who at the time was boarding them and who naturally looked forward to needing their services on his contract work in the future. There were several months when the Bear Valley Irrigation Company was paying (for it afterwards did pay the labor force) at the rate of $2 75 per day to fully 20 men engaged on common labor duty, and doing not more than $1 37½ worth of work each. This is a sample; there are others as bad. It would be useless to cite more of them.

SCHEDULE.—Classification of Expenditures.

Santa Ana Canal, Divisions I and II.

Labor.—Teams and drivers	2-horse, $4 00; 4-horse, $6 00 to $7 00 per day	$12 643 03	
Laborers	$2 00 to $2 75 per day ($2 00)	38 148 80	
Drillers	2 25 to 2 75 " (2 75)	5 630 56	
Powdermen	2 25 to 2 75 " (2 75)	470 75	
Masons	3 00 to 3 50 " (3 00)	2 506 16	
Carpenters	2 75 to 3 00 " (3 00)	5 060 78	
Blacksmiths	2 50 to 3 25 " (3 00)	1 258 24	
Foremen and timekeepers	3 00 to 3 50 " (3 00)	6 970 56	
Total labor			$72 688 88
Materials.—Lumber.—Surf. R. W. flume staves	312 375 ft. @ $32 25 per M.		
Surf. R. W. tunnel staves	35 066 " " "		
Surf R. W. pipe staves	4 335 " " "		
Rough red wood	60 483 " $24 to $30 "		
Surf. Oregon pine	43 275 " $24 62½ "		
Rough Oregon pine	339 891 " { $19 12½ contract, $21 to $26 small lots.		
Old Oregon pine	7 575		
Total for lumber		$20 964 59	
Iron and Steel.—Bridge steel	135 750 lbs. @ 4.7 cents per pound.		
Cast-iron (comb. spans)	10 214 " 3.05 " "		
Wrought iron (comb. spans)	29 684 " 3.85 " "		
Flume iron (cast and wrought)	214 100 " 5.25 " "		
Iron and steel (sundries)	8 444 " 3.25 to 5.00 " "		
Nails and spikes	4 068 " 2.50 to 3.20 " "		
Total for iron and steel		21 131 95	
Cement and Lime. — Cement	2 224 bbls.; contract, $3 10; small lots, $3 50, $3.60		
Lime	954 " " 1 40; " 1 50, 1.70		
Total lime and cement		8 188 55	
Powder, caps and fuse	10 945 lbs. @ 10 to 14 cts. per pound powder	1 366 72	
Oakum	1 675 " 8.5 " " about	139 30	
Paint, asphaltum, etc.		212 00	
Brick		54 69	
Blacksmiths' coal	7 250 lbs @ $17 to $20 per ton	77 00	
Zinc (used up)		12 00	
Tiling, tunnel drains		18 00	
Manilla rope (used upon skidways)		200 00	
			52 364 80
Contract Work.—Labor and Materials.—Hauling	at 37½ cts. per ton mile	$3 616 93	
Wooden pipe (separate statements)		12 266 21	
Canal excavation	at 24 cts. per cubic yard	8 683 62	
Tunnels and approaches	($41 538 96 — $1 508 90 rebates, etc.)	40 030 06	
Total for contract work			64 546 82
Total for labor, materials and contracts			$189 600 50

Notes on Above Schedule.—

The usual labor rates are shown in brackets.

Drillers and powdermen worked much time at common labor work.

Much of the masonry of canal work was done by common labor.

Final Summary of Cost.

The following summarization exhibits in most compact form the cost of each class of structure for each division and for the entire work:

Classification.	Division I.	Division II.	Total.
Headworks and temporary supply ditch	$1 151 45		$1 151 45
Walled canal	1 246 23		1 246 23
Tunnels and connections	47 496 03		47 496 03
Pipes and substructures (wood)	20 727 09		20 727 09
Flumes and substructures (wood)	51 392 48	$7 141 29	58 533 77
Flume and steel bridge		12 588 57	12 588 57
Lined canals		30 165 84	30 165 84
Junction bays	4 233 01	432 50	4 665 51
Sand-boxes	2 118 00		2 118 00
Wasteways	935 47		935 47
Zanja superpassage		221 03	221 03
Pipe connection		178 25	178 25
Totals	$129 299 76	$50 727 48	$180,027 24
General expense	$1 775 98	$495 48	$2 271 46
Unapportioned subdelivery	421 08		421 08
Skidways	1 232 36		1 232 36
Road bridges over canal	75 05	168 30	243 35
Roads	4 178 87	1 226 16	5 405 03
Totals	$7 683 34	$1 889 94	$9 573 28
Grand totals	$136 983 10	$52 617 42	$189 600 52

This account does not include $1 000 rebate on tunnel work provided for in the contract, nor $508 90 penalties on tunnel work, reported under terms of the contract. Including these, the total would be brought to $191 109 42. The total on the final estimate of this work was $167 000, not including the last three items above enumerated. Leaving the amount of those items out from the result, the total becomes $182 719 78. Excess over estimate, $15 719 78, or about 8.6 per cent. A careful revision and checking of cost accounts, made on the basis of notes and data heretofore spoken of, afford ground for the assertion that under normal financial conditions and good superintendence, the work could easily have been built for $25 000 less than it did cost, or, say, $158 000, as against the $167 000 of the estimate.

Roads were and are regarded as a permanent property aside from the aqueduct, and hence should so be estimated and scheduled. Construction apparatus and skidways were regarded as part of the company's plant, available for use on other portions of the work and on other works which it has to build. The deterioration of plant should be

charged against this work, but has not been because there has been no opportunity to ascertain it. The general expense item includes amounts for superintendence, clearing brush along line of work, general cleaning up and collecting odds and ends at close of work, etc., and unapportioned yard and mill work. The unapportioned subdelivery is nearly all for subdelivery of cement, lime and bricks, chargeable to tunnels and other masonry structures and footings. The item is so small and would be so much divided that it would not materially affect rates, even if it could be apportioned.

The total cost of works above itemized in division I, $129 299 76, is at the rate of $37 564 per mile. The $50 727 48 for division II represents $24 528 per mile. The mean cost for the entire work, leaving out, as above, general expense and unapportioned items and outside expenditures, was $32 673 per mile, or $272 per mile per second-foot of capacity. But this is not a fair view to take of the construction. It is built for far more than 120 second-feet. At a comparatively small additional expenditure its capacity will be for 240 second-feet. A rough estimate of completion for this amount, based on the experience thus far had, brings the total cost at materially less than $220 000, or $39 900 per mile, or $166 per mile per second-foot. This result would be decidedly cheap for a work of the class and degree of permanence—one which will lose practically no water whatever, except by evaporation—built through an exceptionally rough country as this is.

Of those who participated in this work the following are deserving of special acknowledgment for faithful, energetic and intelligent service : Mr. John H. Quinton, Jr., Principal Assistant Engineer, in general charge of the office and of field engineering ; Mr. A. Barmann, Civil Engineer, who designed the Mill Creek steel bridge ; Mr. James Black, General Mechanical Assistant in office; Messrs. A. L. Sloane and G. W. Sergeant, Engineers in Charge, divisions I and II, respectively ; Mr. W. P. Edwards, C. E., who did most of the finer instrumental work of the surveys ; and Mr. M. L. Slocum, superintendent of the mechanics' (not the general labor) force. Mr. E. M. Boggs, C. E., was in charge of the preliminary surveys for this work, and no small measure of credit is due him for his share in the selection of the general line afterwards located and built upon. The steel bridge work at Massillon was subjected to the inspection of William Barclay Parsons, M. Am. Soc. C. E., and the excellent character of the work and care exercised in loading were no doubt due in no small degree to his service and instruction.